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2020

PARTICLE PHYSICS BOOKLET

Extracted from the *Review of Particle Physics*
P.A. Zyla *et al*. (Particle Data Group),
Prog. Theor. Exp. Phys. 2020, 083C01 (2020).

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P.A. Zyla *et al* (PDG), Prog. Theor. Exp. Phys. **2020**, 083C01 (2020)

Particle Data Group

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* This *Particle Physics Booklet* includes the Summary Tables plus essential tables, figures, and equations from selected review articles. The table of contents, on the following pages, lists also additional material available in the full *Review*.

PARTICLE PHYSICS BOOKLET TABLE OF CONTENTS

The following are found only in the full *Review*, see

`http://pdg.lbl.gov`

VOLUME 1: SUMMARY TABLES AND REVIEWS

Notes in the Listings

Table 1.1. Revised 2019 by C.G. Wohl (LBNL). Mainly from "CODATA Recommended Values of the Fundamental Physical Constants: 2018," E. Tiesinga, D.B. Newell, P.J. Mohr, and B.N. Taylor, NIST SP961 (May 2019). The last group, beginning with the Fermi coupling constant, comes from PDG. The 1-σ uncertainties are given in parentheses. See the full *Review* for references and further explanation.

Quantity	Symbol, equation	Value	Uncertainty (ppb)
speed of light in vacuum	c	299 792 458 m s^{-1}	exact
Planck constant	h	6.626 070 15$\times10^{-34}$ J s (or J/Hz)$^\sharp$	exact
Planck constant, reduced	$\hbar \equiv h/2\pi$	1.054 571 817...$\times10^{-34}$ J s = 6.582 119 569...$\times10^{-22}$ MeV s	exact
electron charge magnitude	e	1.602 176 634$\times10^{-19}$ C	exact
conversion constant	$\hbar c$	197.326 980 4... MeV fm	exact
conversion constant	$(\hbar c)^2$	0.389 379 372 1... GeV^2 mbarn	exact
electron mass	m_e	0.510 998 950 00(15) MeV/c^2 = 9.109 383 7015(28)$\times10^{-31}$ kg	0.30
proton mass	m_p	938.272 088 16(29) MeV/c^2 = 1.672 621 923 69(51)$\times10^{-27}$ kg	0.31
		= 1.007 276 466 621(53) u = 1836.152 673 43(11) m_e	0.053, 0.060
neutron mass	m_n	939.565 420 52(54) MeV/c^2 = 1.008 664 915 95(49) u	0.57, 0.48
deuteron mass	m_d	1875.612 942 57(57) MeV/c^2	0.30
unified atomic mass unit (u)	u = (mass ^{12}C atom)/12	931.494 102 42(28) MeV/c^2 = 1.660 539 066 60(50)$\times10^{-27}$ kg	0.30
permittivity of free space	$\epsilon_0 = 1/\mu_0 c^2$	8.854 187 8128(13) $\times10^{-12}$ F m^{-1}	0.15
permeability of free space	$\mu_0/(4\pi\times10^{-7})$	1.000 000 000 55(15) N A^{-2}	0.15
fine-structure constant	$\alpha = e^2/4\pi\epsilon_0\hbar c$ (at $Q^2=0$)	7.297 352 5693(11)$\times10^{-3}$ = 1/137.035 999 084(21)	0.15
		At $Q^2 \approx m_W^2$ the value is $\sim$ 1/128.	
classical electron radius	$r_e = e^2/4\pi\epsilon_0 m_e c^2$	2.817 940 3262(13)$\times10^{-15}$ m	0.45
(e^- Compton wavelength)/2π	$\lambda\!\!\!^{-}_e = \hbar/m_e c = r_e\alpha^{-1}$	3.861 592 6796(12)$\times10^{-13}$ m	0.30
Bohr radius ($m_{\text{nucleus}}=\infty$)	$a_\infty = 4\pi\epsilon_0\hbar^2/m_e e^2 = r_e\alpha^{-2}$	0.529 177 210 903(80)$\times10^{-10}$ m	0.15
wavelength of 1 eV/c particle	$hc/(1\text{ eV})$	1.239 841 984... $\times 10^{-6}$ m	exact
Rydberg energy	$hcR_\infty = m_e e^4/2(4\pi\epsilon_0)^2\hbar^2 = m_e c^2\alpha^2/2$	13.605 693 122 994(26) eV	1.9$\times10^{-3}$
Thomson cross section	$\sigma_T = 8\pi r_e^2/3$	0.665 245 873 21(60) barn	0.91

Bohr magneton	$\mu_B = e\hbar/2m_e$	$5.788\ 381\ 8060(17)\times10^{-11}$ MeV T^{-1}	0.3
nuclear magneton	$\mu_N = e\hbar/2m_p$	$3.152\ 451\ 258\ 44(96)\times10^{-14}$ MeV T^{-1}	0.31
electron cyclotron freq./field	$\omega^e_{\rm cycl}/B = e/m_e$	$1.758\ 820\ 010\ 76(53)\times10^{11}$ rad s^{-1} T^{-1}	0.30
proton cyclotron freq./field	$\omega^p_{\rm cycl}/B = e/m_p$	$9.578\ 833\ 1560(29)\times10^{7}$ rad s^{-1} T^{-1}	0.31
gravitational constant	G_N	$6.674\ 30(15)\times10^{-11}$ m^3 kg^{-1} s^{-2}	2.2×10^4
		$= 6.708\ 83(15)\times10^{-39}\ \hbar c\ ({\rm GeV}/c^2)^{-2}$	2.2×10^4
standard gravitational accel.	g_N	$9.806\ 65$ m s^{-2}	exact
Avogadro constant	N_A	$6.022\ 140\ 76\times10^{23}$ mol^{-1}	exact
Boltzmann constant	k	$1.380\ 649\times10^{-23}$ J K^{-1}	exact
		$= 8.617\ 333\ 262\ldots\times10^{-5}$ eV K^{-1}	exact
molar volume, ideal gas at STP	$N_Ak(273.15\ {\rm K})/(101\ 325\ {\rm Pa})$	$22.413\ 969\ 54\ldots\times10^{-3}$ m^3 mol^{-1}	exact
Wien displacement law constant	$b = \lambda_{\rm max}T$	$2.897\ 771\ 955\ldots\times10^{-3}$ m K	exact
Stefan-Boltzmann constant	$\sigma = \pi^2k^4/60\hbar^3c^2$	$5.670\ 374\ 419\ldots\times10^{-8}$ W m^{-2} K^{-4}	exact
Fermi coupling constant	$G_F/(\hbar c)^3$	$1.166\ 378\ 7(6)\times10^{-5}$ GeV^{-2}	510
weak-mixing angle	$\sin^2\widehat{\theta}(M_Z)$ ($\overline{\rm MS}$)	0.231 21(4)	1.7×10^5
$W^\pm$ boson mass	m_W	80.379(12) GeV/c^2	1.5×10^5
Z^0 boson mass	m_Z	91.1876(21) GeV/c^2	2.3×10^4
strong coupling constant	$\alpha_s(m_Z)$	0.1179(10)	8.5×10^6

$\pi = 3.141\ 592\ 653\ 589\ 793\ 238\ldots$ $\quad$ $e = 2.718\ 281\ 828\ 459\ 045\ 235\ldots$ $\quad$ $\gamma = 0.577\ 215\ 664\ 901\ 532\ 860\ldots$

1 in $\equiv$ 0.0254 m	1 G $\equiv 10^{-4}$ T	1 eV $= 1.602\ 176\ 634\times10^{-19}$ J (exact)	kT at 300 K $= [38.681\ 740(22)]^{-1}$ eV
1 Å $\equiv$ 0.1 nm	1 dyne $\equiv 10^{-5}$ N	$(1\ {\rm kg})c^2 = 5.609\ 588\ 603\ldots\times10^{35}$ eV (exact)	0 °C $\equiv$ 273.15 K
1 barn $\equiv 10^{-28}$ m^2	1 erg $\equiv 10^{-7}$ J	1 C $= 2.997\ 924\ 58\times10^9$ esu	1 atmosphere $\equiv$ 760 Torr $\equiv$ 101 325 Pa

Table 2.1: Revised August 2019 by D.E. Groom (LBNL) and D. Scott (U. of British Columbia). The figures in parentheses after some values give the 1-σ uncertainties in the last digit(s). Physical constants are from Ref. [1]. While every effort has been made to obtain the most accurate current values of the listed quantities, the table does not represent a critical review or adjustment of the constants, and is not intended as a primary reference. The values and uncertainties for the cosmological parameters depend on the exact data sets, priors, and basis parameters used in the fit. Many of the derived parameters reported in this table have non-Gaussian likelihoods. Parameters may be highly correlated, so care must be taken in propagating errors. Unless otherwise specified, cosmological parameters are derived from a 6-parameter ΛCDM cosmology fit to *Planck* cosmic microwave background 2018 temperature (TT) + polarization (TE,EE+lowE) + lensing data [2]. For more information see Ref. [3] and the original papers.

Quantity	Symbol, equation.	Value	Reference,footnote
Newtonian constant of gravitation	G_N	$6.674\,30(15) \times 10^{-11} \mathrm{m}^3\,\mathrm{kg}^{-1}\,\mathrm{s}^{-2}$	[1]
Planck mass	$M_P = \sqrt{\hbar c/G_N}$	$1.220\,890(14) \times 10^{19}$ GeV$/c^2 = 2.176\,434(24) \times 10^{-8}$ kg	[1]
Planck length	$l_P = \sqrt{\hbar G_N/c^3}$	$1.616\,255(18) \times 10^{-35}$ m	[1]
tropical year (equinox to equinox, 2020)	yr	$31\,556\,925.1$ s $= 365.242\,189$ days	[4]
sidereal year (period of Earth around Sun relative to stars)		$31\,558\,149.8$ s $\approx \pi \times 10^7$ s	[4]
mean sidereal day (Earth rotation period relative to stars)		$23^{\mathrm{h}}\,56^{\mathrm{m}}\,04\overset{\mathrm{s}}{.}090\,53$	[4]
astronomical unit	au	$149\,597\,870\,700$ m	exact [5]
parsec (1 au/1 arc sec)	pc	$3.085\,677\,581\,49 \times 10^{16}$ m $= 3.261\,56\ldots$ ly	exact [6]
light year (deprecated unit)	ly	$0.306\,601\ldots$ pc $= 0.946\,073\ldots \times 10^{16}$ m	[7]
solid angle	deg^2	$(\pi/180)^2$ sr $= 3.046\,17\ldots \times 10^{-4}$ sr	[8]
Schwarzschild radius of the Sun	$2G_N M_\odot/c^2$	$2.953\,250\,076\,100\,25$ km	[9]
Solar mass	$M_\odot$	$1.988\,41(4) \times 10^{30}$ kg	[10]
nominal Solar equatorial radius	$\mathcal{R}_\odot$	6.957×10^8 m	exact [11]
nominal Solar constant	$\mathcal{S}_\odot$	1361 W m^{-2}	exact [11,12]
nominal Solar photosphere temperature	$\mathcal{T}_\odot$	5772 K	exact [11]
nominal Solar luminosity	$\mathcal{L}_\odot$	3.828×10^{26} W	exact [11,13]
Schwarzschild radius of the Earth	$2G_N M_\oplus/c^2$	$8.870\,055\,940$ mm	[9]
Earth mass	$M_\oplus$	$5.972\,17(13) \times 10^{24}$ kg	[10]
nominal Earth equatorial radius	$\mathcal{R}_\oplus$	6.3781×10^6 m	exact [11]
Chandrasekhar mass	M_{Ch}	$3.097\,972\,\mu^{-2}\,M_P^3/m_H^2 = 1.433\,77(6)\,(\mu/2)^{-2}\,M_\odot$	[14,15]
Eddington luminosity	L_{Ed}	$1.257\,065\,179\,8(12) \times 10^{31}\,(M/M_\odot)$ W $= 3.283\,869\,330\,8(31) \times 10^4\,(M/M_\odot)\,\mathcal{L}_\odot$	[16,17]
jansky (flux density)	Jy	10^{-26} W m^{-2} Hz^{-1}	definition
luminosity conversion	f_0	$3.0128 \times 10^{28} \times 10^{-0.4\,M_{\mathrm{Bol}}}$ W (M_{Bol} = absolute bolometric magnitude = bolometric magnitude at 10 pc)	exact [18]
flux conversion	$\mathcal{F}$	$2.518\,021\,002 \times 10^{-8} \times 10^{-0.4\,m_{\mathrm{Bol}}}$ W m^{-2} (m_{Bol} = apparent bolometric magnitude)	exact [18]
ABsolute monochromatic magnitude	AB	$-2.5\log_{10} f_\nu - 56.10$ (for f_ν in W m^{-2} Hz^{-1}) $= -2.5\log_{10} f_\nu + 8.90$ (for f_ν in Jy)	[19]
Solar angular velocity around Galactic center	Θ_0/R_0	$27.1(5)$ km s^{-1} kpc^{-1}	[20]
Solar distance from Galactic center	R_0	8.178 ± 0.013(stat.) ± 0.022(sys.) kpc	[21,22]
circular velocity at R_0	v_0 or Θ_0	$240(8)$ km s^{-1}	[22,23]
escape velocity from the Galaxy	v_{esc}	492 km s$^{-1} < v_{\mathrm{esc}} < 587$ km s^{-1} (90%)	[24]
local disk density	ρ_{disk}	$6.6(9) \times 10^{-24}$ g cm^{-3} $= 3.7(5)$ GeV$/c^2$ cm^{-3}	[25]
local dark matter density	ρ_χ	canonical value 0.3 GeV$/c^2$ cm^{-3} within factor 2–3	[26]
present-day CMB temperature	T_0	$2.7255(6)$ K	[27,28]
present-day CMB dipole amplitude	d	$3.3621(10)$ mK	[27,29]
Solar velocity with respect to CMB	$v_\odot$	$369.82(11)$ km s^{-1} towards $(l,b) = (264.021(11)^\circ, 48.253(5)^\circ)$	[29]
Local Group velocity with respect to CMB	v_{LG}	$620(15)$ km s^{-1} towards $(l,b) = (271.9(20)^\circ, 29.6(14)^\circ)$	[29]
number density of CMB photons	n_γ	$410.7(3)\,(T/2.7255)^3$ cm^{-3}	[30]
density of CMB photons	ρ_γ	$4.645(4)\,(T/2.7255)^4 \times 10^{-34}$ g cm$^{-3} \approx 0.260$ eV cm^{-3}	[30]

Quantity	Symbol, equation.	Value	Reference,footnote
entropy density/Boltzmann constant	s/k	$2\,891.2\ (T/2.7255)^3\ \mathrm{cm}^{-3}$	[30]
present-day Hubble expansion rate	H_0	$100\ h\ \mathrm{km\,s^{-1}\ Mpc^{-1}} = h \times (9.777\,752\ \mathrm{Gyr})^{-1}$	[31]
scaling factor for Hubble expansion rate	h	0.674(5)	[2, 32]
Hubble length	c/H_0	$0.925\,0629 \times 10^{26}\ h^{-1}\ \mathrm{m} = 1.372(10) \times 10^{26}\ \mathrm{m}$	
scaling for cosmological constant	$c^2/3H_0^2$	$2.85247 \times 10^{51}\ h^{-2}\ \mathrm{m}^2 = 6.21(9) \times 10^{51}\ \mathrm{m}^2$	
critical density of the Universe	$\rho_{\rm crit} = 3H_0^2/8\pi G_N$	$1.878\,34(4) \times 10^{-29}\ h^2\ \mathrm{g\ cm^{-3}}$ $= 1.053\,672(24) \times 10^{-5}\ h^2\ (\mathrm{GeV}/c^2)\ \mathrm{cm}^{-3}$ $= 2.77536627 \times 10^{11}\ h^2\ M_\odot \mathrm{Mpc}^{-3}$	
baryon-to-photon ratio (from BBN)	$\eta = n_{\rm b}/n_\gamma$	$5.8 \times 10^{-10} \le \eta \le 6.5 \times 10^{-10}$ (95% CL)	[33]
number density of baryons	$n_{\rm b}$	$2.515(17) \times 10^{-7}\,\mathrm{cm}^{-3}$ $(2.4 \times 10^{-7} < n_{\rm b} < 2.7 \times 10^{-7})\,\mathrm{cm}^{-3}$ (95% CL, $\eta \times n_\gamma$)	[2, 3, 34, 35]
CMB radiation density of the Universe	$\Omega_\gamma = \rho_\gamma/\rho_{\rm crit}$	$2.473 \times 10^{-5} (T/2.7255)^4\, h^{-2} = 5.38(15) \times 10^{-5}$	[30]
- - - *Planck* 2018 6-parameter fit to flat ΛCDM cosmology - - -			
baryon density of the Universe	$\Omega_{\rm b} = \rho_{\rm b}/\rho_{\rm crit}$	$^\ddagger\,0.02237(15)\,h^{-2}\ = {}^\dagger\,0.0493(6)$	[2, 3, 27]
cold dark matter density of the Universe	$\Omega_{\rm c} = \rho_c/\rho_{\rm crit}$	$^\ddagger\,0.1200(12)\,h^{-2}\ = {}^\dagger\,0.265(7)$	[2, 3, 27]
100 × approx to $r_*/D_{\rm A}$	$100 \times \theta_{\rm MC}$	‡ 1.04092(31)	[2, 3, 27]
reionization optical depth	τ	‡ 0.054(7)	[2, 3, 27]
ln(power prim. curv. pert.) ($k_0 = 0.05\,\mathrm{Mpc}^{-1}$)	$\ln(10^{10}\Delta^2_{\mathcal{R}})$	‡ 3.044(14)	[2, 3, 27]
scalar spectral index	$n_{\rm s}$	‡ 0.965(4)	[2, 3, 27]
pressureless matter parameter	$\Omega_{\rm m} = \Omega_{\rm c} + \Omega_{\rm b}$	† 0.315(7)	[2, 3]
dark energy density parameter	Ω_Λ	† 0.685(7)	[2, 3]
energy density of dark energy	ρ_Λ	$^\dagger\,5.83(16) \times 10^{-30}\,\mathrm{g\,cm^{-3}}$	[2]
cosmological constant	Λ	$^\dagger\,1.088(30) \times 10^{-56}\,\mathrm{cm}^{-2}$	[2]
fluctuation amplitude at $8\,h^{-1}$ Mpc scale	σ_8	† 0.811(6)	[2, 3]
redshift of matter-radiation equality	$z_{\rm eq}$	† 3402(26)	[2, 36]
age at matter-radiation equality	$t_{\rm eq}$	† 51.1(8) kyr	[2, 37]
redshift at which optical depth equals unity	z_*	† 1089.92(25)	[2]
comoving size of sound horizon at z_*	r_*	† 144.43(26) Mpc	[2, 38]
age when optical depth equals unity	t_*	† 372.9(10) kyr	[2, 37]
redshift at half reionization	$z_{\rm i}$	† 7.7(7)	[2, 39]
age at half reionization	$t_{\rm i}$	† 690(90) Myr	[2]
redshift when acceleration was zero	z_q	† 0.636(18)	[2, 37]
age when acceleration was zero	t_q	† 7.70(10) Gyr	[2]
age of the Universe today	t_0	† 13.797(23) Gyr	[2]
effective number of neutrinos	$N_{\rm eff}$	$^\sharp$ 2.99(17)	[2, 40, 41]
sum of neutrino masses	Σm_ν	$^\sharp$ < 0.12 eV (95%, CMB + BAO); ≥ 0.06 eV (mixing)	[2, 41–43]
neutrino density of the Universe	$\Omega_\nu = h^{-2}\Sigma m_{\nu_j}/93.14\,\mathrm{eV}$	$^\sharp$ < 0.003 (95%, CMB + BAO); ≥ 0.0012 (mixing)	[2, 42, 43]
curvature	Ω_K	$^\sharp$ 0.0007(19)	[2]
running spectral index, $k_0 = 0.05\,\mathrm{Mpc}^{-1}$	$dn_{\rm s}/d\ln k$	$^\sharp$ −0.004(7)	[2]
tensor-to-scalar field perturbations ratio,	$r_{0.002} = T/S$	$^\sharp$ < 0.058 (95% CL, $k_0 = 0.002\,\mathrm{Mpc}^{-1}$, no running)	[2, 44, 45]
dark energy equation of state parameter	w	−1.028(31)	[2, 46]
primordial helium fraction	$Y_{\rm p}$	0.245(4)	[47]

‡ Parameter in 6-parameter ΛCDM fit; † Derived parameter in 6-parameter ΛCDM fit; $^\sharp$ Extended model parameter, *Planck* + BAO data [2]

SUMMARY TABLES OF PARTICLE PROPERTIES

Extracted from the Particle Listings of the
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P.A. Zyla *et al.* (Particle Data Group),
Prog. Theor. Exp. Phys. **2020**, 083C01 (2020)
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(Approximate closing date for data: January 15, 2020)

GAUGE AND HIGGS BOSONS

γ (photon)

$I(J^{PC}) = 0,1(1^{--})$

Mass $m < 1 \times 10^{-18}$ eV
Charge $q < 1 \times 10^{-46}$ e (mixed charge)
Charge $q < 1 \times 10^{-35}$ e (single charge)
Mean life τ = Stable

g or gluon

$I(J^{P}) = 0(1^{-})$

Mass $m = 0$ [a]
SU(3) color octet

graviton

$J = 2$

Mass $m < 6 \times 10^{-32}$ eV

W

$J = 1$

Charge = ± 1 e
Mass $m = 80.379 \pm 0.012$ GeV
W/Z mass ratio = 0.88147 ± 0.00013
$m_Z - m_W = 10.809 \pm 0.012$ GeV
$m_{W^+} - m_{W^-} = -0.029 \pm 0.028$ GeV
Full width $\Gamma = 2.085 \pm 0.042$ GeV
$\langle N_{\pi^\pm} \rangle = 15.70 \pm 0.35$
$\langle N_{K^\pm} \rangle = 2.20 \pm 0.19$
$\langle N_{p} \rangle = 0.92 \pm 0.14$
$\langle N_{\text{charged}} \rangle = 19.39 \pm 0.08$

W^- modes are charge conjugates of the modes below.

W^+ DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\ell^+ \nu$	[b]	(10.86 ± 0.09) %		–
$e^+ \nu$		(10.71 ± 0.16) %		40189
$\mu^+ \nu$		(10.63 ± 0.15) %		40189
$\tau^+ \nu$		(11.38 ± 0.21) %		40170

hadrons		(67.41 ± 0.27) %		–
$\pi^+\gamma$		< 7 $\times 10^{-6}$	95%	40189
$D_s^+\gamma$		< 1.3 $\times 10^{-3}$	95%	40165
cX		(33.3 ± 2.6) %		–
$c\overline{s}$		$(31\ ^{+13}_{-11})$ %		–
invisible	[c]	(1.4 ± 2.9) %		–
$\pi^+\pi^+\pi^-$		< 1.01 $\times 10^{-6}$	95%	40189

Z

$J = 1$

Charge = 0
Mass $m = 91.1876 \pm 0.0021$ GeV [d]
Full width $\Gamma = 2.4952 \pm 0.0023$ GeV
$\Gamma(\ell^+\ell^-) = 83.984 \pm 0.086$ MeV [b]
$\Gamma(\text{invisible}) = 499.0 \pm 1.5$ MeV [e]
$\Gamma(\text{hadrons}) = 1744.4 \pm 2.0$ MeV
$\Gamma(\mu^+\mu^-)/\Gamma(e^+e^-) = 1.0001 \pm 0.0024$
$\Gamma(\tau^+\tau^-)/\Gamma(e^+e^-) = 1.0020 \pm 0.0032$ [f]

Average charged multiplicity

$\langle N_{charged}\rangle = 20.76 \pm 0.16$ (S = 2.1)

Couplings to quarks and leptons

$g_V^\ell = -0.03783 \pm 0.00041$
$g_V^u = 0.266 \pm 0.034$
$g_V^d = -0.38^{+0.04}_{-0.05}$
$g_A^\ell = -0.50123 \pm 0.00026$
$g_A^u = 0.519^{+0.028}_{-0.033}$
$g_A^d = -0.527^{+0.040}_{-0.028}$
$g^{\nu_\ell} = 0.5008 \pm 0.0008$
$g^{\nu_e} = 0.53 \pm 0.09$
$g^{\nu_\mu} = 0.502 \pm 0.017$

Asymmetry parameters [g]

$A_e = 0.1515 \pm 0.0019$
$A_\mu = 0.142 \pm 0.015$
$A_\tau = 0.143 \pm 0.004$
$A_s = 0.90 \pm 0.09$
$A_c = 0.670 \pm 0.027$
$A_b = 0.923 \pm 0.020$

Charge asymmetry (%) at Z pole

$A_{FB}^{(0\ell)} = 1.71 \pm 0.10$
$A_{FB}^{(0u)} = 4 \pm 7$
$A_{FB}^{(0s)} = 9.8 \pm 1.1$
$A_{FB}^{(0c)} = 7.07 \pm 0.35$
$A_{FB}^{(0b)} = 9.92 \pm 0.16$

Z DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
e^+e^-	[h]	(3.3632±0.0042) %		45594
$\mu^+\mu^-$	[h]	(3.3662±0.0066) %		45594

$\tau^+\tau^-$	[h]	(3.3696±0.0083) %			45559
$\ell^+\ell^-$	[b,h]	(3.3658±0.0023) %			–
$\ell^+\ell^-\ell^+\ell^-$	[i]	(4.63 ±0.21) $\times 10^{-6}$			45594
invisible	[h]	(20.000 ±0.055) %			–
hadrons	[h]	(69.911 ±0.056) %			–
$(u\overline{u}+c\overline{c})/2$		(11.6 ±0.6) %			–
$(d\overline{d}+s\overline{s}+b\overline{b})/3$		(15.6 ±0.4) %			–
$c\overline{c}$		(12.03 ±0.21) %			–
$b\overline{b}$		(15.12 ±0.05) %			–
$b\overline{b}b\overline{b}$		(3.6 ±1.3) $\times 10^{-4}$			–
ggg		$<$ 1.1 %		CL=95%	–
$\pi^0\gamma$		$<$ 2.01	$\times 10^{-5}$	CL=95%	45594
$\eta\gamma$		$<$ 5.1	$\times 10^{-5}$	CL=95%	45592
$\rho^0\gamma$		$<$ 2.5	$\times 10^{-5}$	CL=95%	45591
$\omega\gamma$		$<$ 6.5	$\times 10^{-4}$	CL=95%	45590
$\eta'(958)\gamma$		$<$ 4.2	$\times 10^{-5}$	CL=95%	45589
$\phi\gamma$		$<$ 9	$\times 10^{-7}$	CL=95%	45588
$\gamma\gamma$		$<$ 1.46	$\times 10^{-5}$	CL=95%	45594
$\pi^0\pi^0$		$<$ 1.52	$\times 10^{-5}$	CL=95%	45594
$\gamma\gamma\gamma$		$<$ 2.2	$\times 10^{-6}$	CL=95%	45594
$\pi^\pm W^\mp$	[j]	$<$ 7	$\times 10^{-5}$	CL=95%	10167
$\rho^\pm W^\mp$	[j]	$<$ 8.3	$\times 10^{-5}$	CL=95%	10142
$J/\psi(1S)$X		(3.51 $^{+0.23}_{-0.25}$)	$\times 10^{-3}$	S=1.1	–
$J/\psi(1S)\gamma$		$<$ 1.4	$\times 10^{-6}$	CL=95%	45541
$\psi(2S)$X		(1.60 ±0.29)	$\times 10^{-3}$		–
$\psi(2S)\gamma$		$<$ 4.5	$\times 10^{-6}$	CL=95%	45519
$J/\psi(1S)J/\psi(1S)$		$<$ 2.2	$\times 10^{-6}$	CL=95%	45489
$\chi_{c1}(1P)$X		(2.9 ±0.7)	$\times 10^{-3}$		–
$\chi_{c2}(1P)$X		$<$ 3.2	$\times 10^{-3}$	CL=90%	–
$\Upsilon(1S)$ X $+\Upsilon(2S)$ X $+\Upsilon(3S)$ X		(1.0 ±0.5)	$\times 10^{-4}$		–
$\Upsilon(1S)$X		$<$ 3.4	$\times 10^{-6}$	CL=95%	–
$\Upsilon(1S)\gamma$		$<$ 2.8	$\times 10^{-6}$	CL=95%	45103
$\Upsilon(2S)$X		$<$ 6.5	$\times 10^{-6}$	CL=95%	–
$\Upsilon(2S)\gamma$		$<$ 1.7	$\times 10^{-6}$	CL=95%	45043
$\Upsilon(3S)$X		$<$ 5.4	$\times 10^{-6}$	CL=95%	–
$\Upsilon(3S)\gamma$		$<$ 4.8	$\times 10^{-6}$	CL=95%	45006
$\Upsilon(1,2,3S)\ \Upsilon(1,2,3S)$		$<$ 1.5	$\times 10^{-6}$	CL=95%	–
$(D^0/\overline{D}^0)$ X		(20.7 ±2.0) %			–
$D^\pm$X		(12.2 ±1.7) %			–
$D^*(2010)^\pm$X	[j]	(11.4 ±1.3) %			–
$D_{s1}(2536)^\pm$X		(3.6 ±0.8)	$\times 10^{-3}$		–
$D_{sJ}(2573)^\pm$X		(5.8 ±2.2)	$\times 10^{-3}$		–
B^+X	[k]	(6.08 ±0.13) %			–
B^0_sX	[k]	(1.59 ±0.13) %			–
Λ^+_cX		(1.54 ±0.33) %			–
b-baryon X	[k]	(1.38 ±0.22) %			–
anomalous $\gamma+$ hadrons	[l]	$<$ 3.2	$\times 10^{-3}$	CL=95%	–
$e^+e^-\gamma$	[l]	$<$ 5.2	$\times 10^{-4}$	CL=95%	45594
$\mu^+\mu^-\gamma$	[l]	$<$ 5.6	$\times 10^{-4}$	CL=95%	45594
$\tau^+\tau^-\gamma$	[l]	$<$ 7.3	$\times 10^{-4}$	CL=95%	45559
$\ell^+\ell^-\gamma\gamma$	[n]	$<$ 6.8	$\times 10^{-6}$	CL=95%	–
$q\overline{q}\gamma\gamma$	[n]	$<$ 5.5	$\times 10^{-6}$	CL=95%	–
$\nu\overline{\nu}\gamma\gamma$	[n]	$<$ 3.1	$\times 10^{-6}$	CL=95%	45594

$e^{\pm}\mu^{\mp}$	LF	[j] <	7.5	$\times 10^{-7}$	CL=95%	45594
$e^{\pm}\tau^{\mp}$	LF	[j] <	9.8	$\times 10^{-6}$	CL=95%	45576
$\mu^{\pm}\tau^{\mp}$	LF	[j] <	1.2	$\times 10^{-5}$	CL=95%	45576
$p e$	L,B	<	1.8	$\times 10^{-6}$	CL=95%	45589
$p \mu$	L,B	<	1.8	$\times 10^{-6}$	CL=95%	45589

See Particle Listings for 4 decay modes that have been seen / not seen.

H^0

$J = 0$

Mass $m = 125.10 \pm 0.14$ GeV

Full width $\Gamma < 0.013$ GeV, CL = 95% (assumes equal on-shell and off-shell effective couplings)

H^0 Signal Strengths in Different Channels

Combined Final States = 1.13 ± 0.06

$W W^* = 1.19 \pm 0.12$

$Z Z^* = 1.20^{+0.12}_{-0.11}$

$\gamma\gamma = 1.11^{+0.10}_{-0.09}$

$c\overline{c}$ Final State < 110, CL = 95%

$b\overline{b} = 1.04 \pm 0.13$

$\mu^+\mu^- = 0.6 \pm 0.8$

$\tau^+\tau^- = 1.15^{+0.16}_{-0.15}$

$Z\gamma <$ 6.6, CL = 95%

top Yukawa coupling < 1.7, CL = 95%

$t\overline{t}H^0$ Production = 1.28 ± 0.20

H^0 Production Cross Section in pp Collisions at $\sqrt{s} = 13$ TeV = 59 ± 5 pb

H^0 DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
e^+e^-		$<3.6 \times 10^{-4}$	95%	62550
$J/\psi\gamma$		$<3.5 \times 10^{-4}$	95%	62511
$J/\psi J/\psi$		$<1.8 \times 10^{-3}$	95%	62473
$\psi(2S)\gamma$		$<2.0 \times 10^{-3}$	95%	62495
$\Upsilon(1S)\gamma$		$<4.9 \times 10^{-4}$	95%	62192
$\Upsilon(2S)\gamma$		$<5.9 \times 10^{-4}$	95%	62148
$\Upsilon(3S)\gamma$		$<5.7 \times 10^{-4}$	95%	62121
Υ(nS) Υ(mS)		$<1.4 \times 10^{-3}$	95%	–
$\rho(770)\gamma$		$<8.8 \times 10^{-4}$	95%	62547
$\phi(1020)\gamma$		$<4.8 \times 10^{-4}$	95%	62546
$e\mu$	LF	$<6.1 \times 10^{-5}$	95%	62550
$e\tau$	LF	$<4.7 \times 10^{-3}$	95%	62537
$\mu\tau$	LF	$<2.5 \times 10^{-3}$	95%	62537
γinvisible		<4.6 %	95%	–

Neutral Higgs Bosons, Searches for

Mass limits for heavy neutral Higgs bosons (H^0_2, A^0) in the MSSM

m > 389 GeV, CL = 95% (tanβ = 10)

m > 863 GeV, CL = 95% (tanβ = 20)

m > 1157 GeV, CL = 95% (tanβ = 30)

m > 1341 GeV, CL = 95% (tanβ = 40)

m > 1496 GeV, CL = 95% (tanβ = 50)

m > 1613 GeV, CL = 95% (tanβ = 60)

Charged Higgs Bosons ($H^{\pm}$ and $H^{\pm\pm}$), Searches for

Mass limits for m_{H^+} < m(top)

m > 155 GeV, CL = 95%

Mass limits for m_{H^+} > m(top)

m > 181 GeV, CL = 95% (tanβ = 10)
m > 249 GeV, CL = 95% (tanβ = 20)
m > 390 GeV, CL = 95% (tanβ = 30)
m > 894 GeV, CL = 95% (tanβ = 40)
m > 1017 GeV, CL = 95% (tanβ = 50)
m > 1103 GeV, CL = 95% (tanβ = 60)

New Heavy Bosons (W', Z', leptoquarks, etc.), Searches for

Additional W Bosons

W' with standard couplings
Mass $m >$ 5200 GeV, CL = 95% (pp direct search)
W_R (Right-handed W Boson)
Mass $m >$ 715 GeV, CL = 90% (electroweak fit)

Additional Z Bosons

Z'_{SM} with standard couplings
Mass $m >$ 4.500 × 10^3 GeV, CL = 95% (pp direct search)
Z_{LR} of $SU(2)_L \times SU(2)_R \times U(1)$ (with $g_L = g_R$)
Mass $m >$ 630 GeV, CL = 95% ($p\overline{p}$ direct search)
Mass $m >$ 1162 GeV, CL = 95% (electroweak fit)
Z_χ of SO(10) → $SU(5)\times U(1)_\chi$ (with $g_\chi = e/\cos\theta_W$)
Mass $m >$ 4.100 × 10^3 GeV, CL = 95% (pp direct search)
Z_ψ of E_6 → $SO(10)\times U(1)_\psi$ (with $g_\psi = e/\cos\theta_W$)
Mass $m >$ 3900 GeV, CL = 95% (pp direct search)
Z_η of E_6 → $SU(3)\times SU(2)\times U(1)\times U(1)_\eta$ (with $g_\eta = e/\cos\theta_W$)
Mass $m >$ 3.900 × 10^3 GeV, CL = 95% (pp direct search)

Scalar Leptoquarks

$m >$ 1050 GeV, CL = 95% (1st gen., pair prod., B($\tau\, t$)=1)
$m >$ 1755 GeV, CL = 95% (1st gen., single prod., B($\tau\, b$)=1)
$m >$ 1420 GeV, CL = 95% (2nd gen., pair prod., B($\mu\, t$)=1)
$m >$ 660 GeV, CL = 95% (2nd gen., single prod., B($\mu\, q$)=1)
$m >$ 900 GeV, CL = 95% (3rd gen., pair prod., B($e\, q$)=1)
$m >$ 740 GeV, CL = 95% (3rd gen., single prod., B($e\, q$)=1)

(See the Particle Listings in the Full *Review of Particle Physics* for assumptions on leptoquark quantum numbers and branching fractions.)

Diquarks

Mass $m >$ 6000 GeV, CL = 95% (E_6 diquark)

Axigluon

Mass $m >$ 6100 GeV, CL = 95%

Axions (A^0) and Other Very Light Bosons, Searches for

See the review on "Axions and other similar particles."

The best limit for the half-life of neutrinoless double beta decay with Majoron emission is $> 7.2 \times 10^{24}$ years (CL = 90%).

NOTES

In this Summary Table:

When a quantity has "(S = ...)" to its right, the error on the quantity has been enlarged by the "scale factor" S, defined as $S = \sqrt{\chi^2/(N-1)}$, where N is the number of measurements used in calculating the quantity.

A decay momentum p is given for each decay mode. For a 2-body decay, p is the momentum of each decay product in the rest frame of the decaying particle. For a 3-or-more-body decay, p is the largest momentum any of the products can have in this frame.

[*a*] Theoretical value. A mass as large as a few MeV may not be precluded.

[*b*] ℓ indicates each type of lepton (e, μ, and τ), not sum over them.

[*c*] This represents the width for the decay of the W boson into a charged particle with momentum below detectability, p< 200 MeV.

[*d*] The Z-boson mass listed here corresponds to a Breit-Wigner resonance parameter. It lies approximately 34 MeV above the real part of the position of the pole (in the energy-squared plane) in the Z-boson propagator.

[*e*] This partial width takes into account Z decays into $\nu\overline{\nu}$ and any other possible undetected modes.

[*f*] This ratio has not been corrected for the τ mass.

[*g*] Here $A \equiv 2g_V g_A/(g_V^2+g_A^2)$.

[*h*] This parameter is not directly used in the overall fit but is derived using the fit results; see the note "The Z boson" and ref. LEP-SLC 06 (Physics Reports (Physics Letters C) **427** 257 (2006)).

[*i*] Here ℓ indicates e or μ.

[*j*] The value is for the sum of the charge states or particle/antiparticle states indicated.

[*k*] This value is updated using the product of (i) the $Z \rightarrow b\overline{b}$ fraction from this listing and (ii) the b-hadron fraction in an unbiased sample of weakly decaying b-hadrons produced in Z-decays provided by the Heavy Flavor Averaging Group (HFLAV, http://www.slac.stanford.edu/xorg/hflav/osc/PDG_2009/#FRACZ).

[*l*] See the Z Particle Listings in the Full *Review of Particle Physics* for the γ energy range used in this measurement.

[*n*] For $m_{\gamma\gamma} = (60 \pm 5)$ GeV.

LEPTONS

e

$J = \frac{1}{2}$

Mass $m = (548.579909070 \pm 0.000000016) \times 10^{-6}$ u
Mass $m = 0.5109989461 \pm 0.0000000031$ MeV
$\left|m_{e^+} - m_{e^-}\right|/m < 8 \times 10^{-9}$, CL = 90%
$\left|q_{e^+} + q_{e^-}\right|/e < 4 \times 10^{-8}$
Magnetic moment anomaly
$(g{-}2)/2 = (1159.65218091 \pm 0.00000026) \times 10^{-6}$
$(g_{e^+} - g_{e^-}) \,/\, g_{\text{average}} = (-0.5 \pm 2.1) \times 10^{-12}$
Electric dipole moment $d < 0.11 \times 10^{-28}$ e cm, CL = 90%
Mean life $\tau > 6.6 \times 10^{28}$ yr, CL = 90% [a]

μ

$J = \frac{1}{2}$

Mass $m = 0.1134289257 \pm 0.0000000025$ u
Mass $m = 105.6583745 \pm 0.0000024$ MeV
Mean life $\tau = (2.1969811 \pm 0.0000022) \times 10^{-6}$ s
$\tau_{\mu^+}/\tau_{\mu^-} = 1.00002 \pm 0.00008$
$c\tau = 658.6384$ m
Magnetic moment anomaly $(g{-}2)/2 = (11659209 \pm 6) \times 10^{-10}$
$(g_{\mu^+} - g_{\mu^-}) \,/\, g_{\text{average}} = (-0.11 \pm 0.12) \times 10^{-8}$
Electric diapole moment $\left|\text{d}\right| < 1.8 \times 10^{-19}$ e cm, CL = 95%

Decay parameters [b]

$\rho = 0.74979 \pm 0.00026$
$\eta = 0.057 \pm 0.034$
$\delta = 0.75047 \pm 0.00034$
$\xi P_\mu = 1.0009^{+0.0016}_{-0.0007}$ [c]
$\xi P_\mu \delta/\rho = 1.0018^{+0.0016}_{-0.0007}$ [c]
$\xi' = 1.00 \pm 0.04$
$\xi'' = 0.98 \pm 0.04$
$\alpha/\text{A} = (0 \pm 4) \times 10^{-3}$
$\alpha'/\text{A} = (-10 \pm 20) \times 10^{-3}$
$\beta/\text{A} = (4 \pm 6) \times 10^{-3}$
$\beta'/\text{A} = (2 \pm 7) \times 10^{-3}$
$\overline{\eta} = 0.02 \pm 0.08$

μ^+ modes are charge conjugates of the modes below.

μ^- DECAY MODES			Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$e^- \overline{\nu}_e \nu_\mu$			$\approx 100\%$		53
$e^- \overline{\nu}_e \nu_\mu \gamma$		[d]	$(6.0 \pm 0.5) \times 10^{-8}$		53
$e^- \overline{\nu}_e \nu_\mu e^+ e^-$		[e]	$(3.4 \pm 0.4) \times 10^{-5}$		53
Lepton Family number (*LF*) violating modes					
$e^- \nu_e \overline{\nu}_\mu$	*LF*	[f]	< 1.2 %	90%	53
$e^- \gamma$	*LF*		$< 4.2 \times 10^{-13}$	90%	53
$e^- e^+ e^-$	*LF*		$< 1.0 \times 10^{-12}$	90%	53
$e^- 2\gamma$	*LF*		$< 7.2 \times 10^{-11}$	90%	53

τ

$J = \frac{1}{2}$

Mass $m = 1776.86 \pm 0.12$ MeV
$(m_{\tau^+} - m_{\tau^-})/m_{\text{average}} < 2.8 \times 10^{-4}$, CL = 90%
Mean life $\tau = (290.3 \pm 0.5) \times 10^{-15}$ s
$c\tau = 87.03$ μm
Magnetic moment anomaly > -0.052 and < 0.013, CL = 95%
$\text{Re}(d_\tau) = -0.220$ to 0.45×10^{-16} $e$cm, CL = 95%
$\text{Im}(d_\tau) = -0.250$ to 0.0080×10^{-16} $e$cm, CL = 95%

Weak dipole moment

$\text{Re}(d^w_\tau) < 0.50 \times 10^{-17}$ $e$cm, CL = 95%
$\text{Im}(d^w_\tau) < 1.1 \times 10^{-17}$ $e$cm, CL = 95%

Weak anomalous magnetic dipole moment

$\text{Re}(\alpha^w_\tau) < 1.1 \times 10^{-3}$, CL = 95%
$\text{Im}(\alpha^w_\tau) < 2.7 \times 10^{-3}$, CL = 95%
$\tau^\pm \to \pi^\pm K^0_S \nu_\tau$ (RATE DIFFERENCE) / (RATE SUM) = (-0.36 ± 0.25)%

Decay parameters

See the τ Particle Listings in the Full *Review of Particle Physics* for a note concerning τ-decay parameters.

$\rho(e \text{ or } \mu) = 0.745 \pm 0.008$
$\rho(e) = 0.747 \pm 0.010$
$\rho(\mu) = 0.763 \pm 0.020$
$\xi(e \text{ or } \mu) = 0.985 \pm 0.030$
$\xi(e) = 0.994 \pm 0.040$
$\xi(\mu) = 1.030 \pm 0.059$
$\eta(e \text{ or } \mu) = 0.013 \pm 0.020$
$\eta(\mu) = 0.094 \pm 0.073$
$(\delta\xi)(e \text{ or } \mu) = 0.746 \pm 0.021$
$(\delta\xi)(e) = 0.734 \pm 0.028$
$(\delta\xi)(\mu) = 0.778 \pm 0.037$
$\xi(\pi) = 0.993 \pm 0.022$
$\xi(\rho) = 0.994 \pm 0.008$
$\xi(a_1) = 1.001 \pm 0.027$
ξ(all hadronic modes) $= 0.995 \pm 0.007$
$\overline{\eta}(\mu)$ PARAMETER $= -1.3 \pm 1.7$
$\xi_\kappa(e)$ PARAMETER $= -0.4 \pm 1.2$
$\xi_\kappa(\mu)$ PARAMETER $= 0.8 \pm 0.6$

τ^+ modes are charge conjugates of the modes below. "$h^\pm$" stands for $\pi^\pm$ or $K^\pm$. "ℓ" stands for e or μ. "Neutrals" stands for γ's and/or π^0's.

τ^- DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Modes with one charged particle				
particle$^- \geq 0$ neutrals $\geq 0K^0\nu_\tau$ ("1-prong")		(85.24 ± 0.06) %		–
particle$^- \geq 0$ neutrals $\geq 0K^0_L\nu_\tau$		(84.58 ± 0.06) %		–
$\mu^-\overline{\nu}_\mu\nu_\tau$	[g]	(17.39 ± 0.04) %		885
$\mu^-\overline{\nu}_\mu\nu_\tau\gamma$	[e]	$(3.67 \pm 0.08) \times 10^{-3}$		885
$e^-\overline{\nu}_e\nu_\tau$	[g]	(17.82 ± 0.04) %		888

$e^- \overline{\nu}_e \nu_\tau \gamma$	[e]	(1.83 ± 0.05) %		888
$h^- \geq 0 K_L^0\ \nu_\tau$		(12.03 ± 0.05) %		883
$h^- \nu_\tau$		(11.51 ± 0.05) %		883
$\pi^- \nu_\tau$	[g]	(10.82 ± 0.05) %		883
$K^- \nu_\tau$	[g]	$(6.96 \pm 0.10) \times 10^{-3}$		820
$h^- \geq 1$ neutrals ν_τ		(37.01 ± 0.09) %		–
$h^- \geq 1\pi^0 \nu_\tau (\text{ex.}K^0)$		(36.51 ± 0.09) %		–
$h^- \pi^0 \nu_\tau$		(25.93 ± 0.09) %		878
$\pi^- \pi^0 \nu_\tau$	[g]	(25.49 ± 0.09) %		878
$\pi^- \pi^0$ non-$\rho(770) \nu_\tau$		$(3.0 \pm 3.2) \times 10^{-3}$		878
$K^- \pi^0 \nu_\tau$	[g]	$(4.33 \pm 0.15) \times 10^{-3}$		814
$h^- \geq 2\pi^0 \nu_\tau$		(10.81 ± 0.09) %		–
$h^- 2\pi^0 \nu_\tau$		(9.48 ± 0.10) %		862
$h^- 2\pi^0 \nu_\tau (\text{ex.}K^0)$		(9.32 ± 0.10) %		862
$\pi^- 2\pi^0 \nu_\tau (\text{ex.}K^0)$	[g]	(9.26 ± 0.10) %		862
$\pi^- 2\pi^0 \nu_\tau (\text{ex.}K^0)$, scalar		$< 9 \times 10^{-3}$	CL=95%	862
$\pi^- 2\pi^0 \nu_\tau (\text{ex.}K^0)$, vector		$< 7 \times 10^{-3}$	CL=95%	862
$K^- 2\pi^0 \nu_\tau (\text{ex.}K^0)$	[g]	$(6.5 \pm 2.2) \times 10^{-4}$		796
$h^- \geq 3\pi^0 \nu_\tau$		(1.34 ± 0.07) %		–
$h^- \geq 3\pi^0 \nu_\tau (\text{ex. } K^0)$		(1.25 ± 0.07) %		–
$h^- 3\pi^0 \nu_\tau$		(1.18 ± 0.07) %		836
$\pi^- 3\pi^0 \nu_\tau (\text{ex.}K^0)$	[g]	(1.04 ± 0.07) %		836
$K^- 3\pi^0 \nu_\tau (\text{ex.}K^0, \eta)$	[g]	$(4.8 \pm 2.1) \times 10^{-4}$		765
$h^- 4\pi^0 \nu_\tau (\text{ex.}K^0)$		$(1.6 \pm 0.4) \times 10^{-3}$		800
$h^- 4\pi^0 \nu_\tau (\text{ex.}K^0, \eta)$	[g]	$(1.1 \pm 0.4) \times 10^{-3}$		800
$a_1(1260) \nu_\tau \to \pi^- \gamma \nu_\tau$		$(3.8 \pm 1.5) \times 10^{-4}$		–
$K^- \geq 0\pi^0 \geq 0K^0 \geq 0\gamma\ \nu_\tau$		(1.552 ± 0.029) %		820
$K^- \geq 1\ (\pi^0 \text{ or } K^0 \text{ or } \gamma)\ \nu_\tau$		$(8.59 \pm 0.28) \times 10^{-3}$		–

Modes with K^0's

$K_S^0 (\text{particles})^- \nu_\tau$		$(9.43 \pm 0.28) \times 10^{-3}$		–
$h^- \overline{K}^0 \nu_\tau$		$(9.87 \pm 0.14) \times 10^{-3}$		812
$\pi^- \overline{K}^0 \nu_\tau$	[g]	$(8.38 \pm 0.14) \times 10^{-3}$		812
$\pi^- \overline{K}^0 (\text{non-}K^*(892)^-) \nu_\tau$		$(5.4 \pm 2.1) \times 10^{-4}$		812
$K^- K^0 \nu_\tau$	[g]	$(1.486 \pm 0.034) \times 10^{-3}$		737
$K^- K^0 \geq 0\pi^0 \nu_\tau$		$(2.99 \pm 0.07) \times 10^{-3}$		737
$h^- \overline{K}^0 \pi^0 \nu_\tau$		$(5.32 \pm 0.13) \times 10^{-3}$		794
$\pi^- \overline{K}^0 \pi^0 \nu_\tau$	[g]	$(3.82 \pm 0.13) \times 10^{-3}$		794
$\overline{K}^0 \rho^- \nu_\tau$		$(2.2 \pm 0.5) \times 10^{-3}$		612
$K^- K^0 \pi^0 \nu_\tau$	[g]	$(1.50 \pm 0.07) \times 10^{-3}$		685
$\pi^- \overline{K}^0 \geq 1\pi^0 \nu_\tau$		$(4.08 \pm 0.25) \times 10^{-3}$		–
$\pi^- \overline{K}^0 \pi^0 \pi^0 \nu_\tau (\text{ex.}K^0)$	[g]	$(2.6 \pm 2.3) \times 10^{-4}$		763
$K^- K^0 \pi^0 \pi^0 \nu_\tau$		$< 1.6 \times 10^{-4}$	CL=95%	619
$\pi^- K^0 \overline{K}^0 \nu_\tau$		$(1.55 \pm 0.24) \times 10^{-3}$		682
$\pi^- K_S^0 K_S^0 \nu_\tau$	[g]	$(2.35 \pm 0.06) \times 10^{-4}$		682
$\pi^- K_S^0 K_L^0 \nu_\tau$	[g]	$(1.08 \pm 0.24) \times 10^{-3}$		682
$\pi^- K_L^0 K_L^0 \nu_\tau$		$(2.35 \pm 0.06) \times 10^{-4}$		682
$\pi^- K^0 \overline{K}^0 \pi^0 \nu_\tau$		$(3.6 \pm 1.2) \times 10^{-4}$		614
$\pi^- K_S^0 K_S^0 \pi^0 \nu_\tau$	[g]	$(1.82 \pm 0.21) \times 10^{-5}$		614
$K^{*-} K^0 \pi^0 \nu_\tau \to \pi^- K_S^0 K_S^0 \pi^0 \nu_\tau$		$(1.08 \pm 0.21) \times 10^{-5}$		–
$f_1(1285) \pi^- \nu_\tau \to \pi^- K_S^0 K_S^0 \pi^0 \nu_\tau$		$(6.8 \pm 1.5) \times 10^{-6}$		–

$f_1(1420)\pi^-\nu_\tau \to \pi^- K^0_S K^0_S \pi^0 \nu_\tau$		$(2.4 \pm 0.8) \times 10^{-6}$		–
$\pi^- K^0_S K^0_L \pi^0 \nu_\tau$	[g]	$(3.2 \pm 1.2) \times 10^{-4}$		614
$\pi^- K^0_L K^0_L \pi^0 \nu_\tau$		$(1.82 \pm 0.21) \times 10^{-5}$		614
$K^- K^0_S K^0_S \nu_\tau$		$< 6.3 \times 10^{-7}$	CL=90%	466
$K^- K^0_S K^0_S \pi^0 \nu_\tau$		$< 4.0 \times 10^{-7}$	CL=90%	337
$K^0 h^+ h^- h^- \geq 0$ neutrals ν_τ		$< 1.7 \times 10^{-3}$	CL=95%	760
$K^0 h^+ h^- h^- \nu_\tau$	[g]	$(2.5 \pm 2.0) \times 10^{-4}$		760

Modes with three charged particles

$h^- h^- h^+ \geq 0$ neutrals $\geq 0 K^0_L \nu_\tau$		(15.20 ± 0.06) %		861
$h^- h^- h^+ \geq 0$ neutrals ν_τ (ex. $K^0_S \to \pi^+\pi^-$) ("3-prong")		(14.55 ± 0.06) %		861
$h^- h^- h^+ \nu_\tau$		(9.80 ± 0.05) %		861
$h^- h^- h^+ \nu_\tau$ (ex.K^0)		(9.46 ± 0.05) %		861
$h^- h^- h^+ \nu_\tau$ (ex.K^0,ω)		(9.43 ± 0.05) %		861
$\pi^-\pi^+\pi^-\nu_\tau$		(9.31 ± 0.05) %		861
$\pi^-\pi^+\pi^-\nu_\tau$ (ex.K^0)		(9.02 ± 0.05) %		861
$\pi^-\pi^+\pi^-\nu_\tau$ (ex.K^0), non-axial vector		< 2.4 %	CL=95%	861
$\pi^-\pi^+\pi^-\nu_\tau$ (ex.K^0,ω)	[g]	(8.99 ± 0.05) %		861
$h^- h^- h^+ \geq 1$ neutrals ν_τ		(5.29 ± 0.05) %		–
$h^- h^- h^+ \geq 1\pi^0 \nu_\tau$ (ex. K^0)		(5.09 ± 0.05) %		–
$h^- h^- h^+ \pi^0 \nu_\tau$		(4.76 ± 0.05) %		834
$h^- h^- h^+ \pi^0 \nu_\tau$ (ex.K^0)		(4.57 ± 0.05) %		834
$h^- h^- h^+ \pi^0 \nu_\tau$ (ex. K^0, ω)		(2.79 ± 0.07) %		834
$\pi^-\pi^+\pi^-\pi^0\nu_\tau$		(4.62 ± 0.05) %		834
$\pi^-\pi^+\pi^-\pi^0\nu_\tau$ (ex.K^0)		(4.49 ± 0.05) %		834
$\pi^-\pi^+\pi^-\pi^0\nu_\tau$ (ex.K^0,ω)	[g]	(2.74 ± 0.07) %		834
$h^- h^- h^+ \geq 2\pi^0 \nu_\tau$ (ex. K^0)		$(5.17 \pm 0.31) \times 10^{-3}$		–
$h^- h^- h^+ 2\pi^0 \nu_\tau$		$(5.05 \pm 0.31) \times 10^{-3}$		797
$h^- h^- h^+ 2\pi^0 \nu_\tau$ (ex.K^0)		$(4.95 \pm 0.31) \times 10^{-3}$		797
$h^- h^- h^+ 2\pi^0 \nu_\tau$ (ex.K^0,ω,η)	[g]	$(10 \pm 4) \times 10^{-4}$		797
$h^- h^- h^+ 3\pi^0 \nu_\tau$		$(2.13 \pm 0.30) \times 10^{-4}$		749
$2\pi^-\pi^+ 3\pi^0 \nu_\tau$ (ex.K^0)		$(1.95 \pm 0.30) \times 10^{-4}$		749
$2\pi^-\pi^+ 3\pi^0 \nu_\tau$ (ex.K^0, η, $f_1(1285)$)		$(1.7 \pm 0.4) \times 10^{-4}$		–
$2\pi^-\pi^+ 3\pi^0 \nu_\tau$ (ex.K^0, η, ω, $f_1(1285)$)	[g]	$(1.4 \pm 2.7) \times 10^{-5}$		–
$K^- h^+ h^- \geq 0$ neutrals ν_τ		$(6.29 \pm 0.14) \times 10^{-3}$		794
$K^- h^+ \pi^- \nu_\tau$ (ex.K^0)		$(4.37 \pm 0.07) \times 10^{-3}$		794
$K^- h^+ \pi^- \pi^0 \nu_\tau$ (ex.K^0)		$(8.6 \pm 1.2) \times 10^{-4}$		763
$K^-\pi^+\pi^- \geq 0$ neutrals ν_τ		$(4.77 \pm 0.14) \times 10^{-3}$		794
$K^-\pi^+\pi^- \geq 0\pi^0 \nu_\tau$ (ex.K^0)		$(3.73 \pm 0.13) \times 10^{-3}$		794
$K^-\pi^+\pi^-\nu_\tau$		$(3.45 \pm 0.07) \times 10^{-3}$		794
$K^-\pi^+\pi^-\nu_\tau$ (ex.K^0)		$(2.93 \pm 0.07) \times 10^{-3}$		794
$K^-\pi^+\pi^-\nu_\tau$ (ex.K^0,ω)	[g]	$(2.93 \pm 0.07) \times 10^{-3}$		794
$K^-\rho^0\nu_\tau \to K^-\pi^+\pi^-\nu_\tau$		$(1.4 \pm 0.5) \times 10^{-3}$		–
$K^-\pi^+\pi^-\pi^0\nu_\tau$		$(1.31 \pm 0.12) \times 10^{-3}$		763
$K^-\pi^+\pi^-\pi^0\nu_\tau$ (ex.K^0)		$(7.9 \pm 1.2) \times 10^{-4}$		763
$K^-\pi^+\pi^-\pi^0\nu_\tau$ (ex.K^0,η)		$(7.6 \pm 1.2) \times 10^{-4}$		763
$K^-\pi^+\pi^-\pi^0\nu_\tau$ (ex.K^0,ω)		$(3.7 \pm 0.9) \times 10^{-4}$		763
$K^-\pi^+\pi^-\pi^0\nu_\tau$ (ex.K^0,ω,η)	[g]	$(3.9 \pm 1.4) \times 10^{-4}$		763
$K^-\pi^+K^- \geq 0$ neut. ν_τ		$< 9 \times 10^{-4}$	CL=95%	685

$K^- K^+ \pi^- \geq 0$ neut. ν_τ		$(1.496 \pm 0.033) \times 10^{-3}$		685
$K^- K^+ \pi^- \nu_\tau$	[g]	$(1.435 \pm 0.027) \times 10^{-3}$		685
$K^- K^+ \pi^- \pi^0 \nu_\tau$	[g]	$(6.1 \pm 1.8) \times 10^{-5}$		618
$K^- K^+ K^- \nu_\tau$		$(2.2 \pm 0.8) \times 10^{-5}$	S=5.4	472
$K^- K^+ K^- \nu_\tau$ (ex. ϕ)		$< 2.5 \times 10^{-6}$	CL=90%	–
$K^- K^+ K^- \pi^0 \nu_\tau$		$< 4.8 \times 10^{-6}$	CL=90%	345
$\pi^- K^+ \pi^- \geq 0$ neut. ν_τ		$< 2.5 \times 10^{-3}$	CL=95%	794
$e^- e^- e^+ \overline{\nu}_e \nu_\tau$		$(2.8 \pm 1.5) \times 10^{-5}$		888
$\mu^- e^- e^+ \overline{\nu}_\mu \nu_\tau$		$< 3.2 \times 10^{-5}$	CL=90%	885
$\pi^- \mu^- \mu^+ \nu_\tau$		$< 1.14 \times 10^{-5}$	CL=90%	870
Modes with five charged particles				
$3h^- 2h^+ \geq 0$ neutrals ν_τ (ex. $K^0_S \to \pi^- \pi^+$) ("5-prong")		$(9.9 \pm 0.4) \times 10^{-4}$		794
$3h^- 2h^+ \nu_\tau$ (ex.K^0)		$(8.29 \pm 0.31) \times 10^{-4}$		794
$3\pi^- 2\pi^+ \nu_\tau$ (ex.K^0, ω)		$(8.27 \pm 0.31) \times 10^{-4}$		794
$3\pi^- 2\pi^+ \nu_\tau$ (ex.K^0, ω, $f_1(1285)$)	[g]	$(7.75 \pm 0.30) \times 10^{-4}$		–
$K^- 2\pi^- 2\pi^+ \nu_\tau$ (ex.K^0)	[g]	$(6 \pm 12) \times 10^{-7}$		716
$K^+ 3\pi^- \pi^+ \nu_\tau$		$< 5.0 \times 10^{-6}$	CL=90%	716
$K^+ K^- 2\pi^- \pi^+ \nu_\tau$		$< 4.5 \times 10^{-7}$	CL=90%	528
$3h^- 2h^+ \pi^0 \nu_\tau$ (ex.K^0)		$(1.65 \pm 0.11) \times 10^{-4}$		746
$3\pi^- 2\pi^+ \pi^0 \nu_\tau$ (ex.K^0)		$(1.63 \pm 0.11) \times 10^{-4}$		746
$3\pi^- 2\pi^+ \pi^0 \nu_\tau$ (ex.K^0, η, $f_1(1285)$)		$(1.11 \pm 0.10) \times 10^{-4}$		–
$3\pi^- 2\pi^+ \pi^0 \nu_\tau$ (ex.K^0, η, ω, $f_1(1285)$)	[g]	$(3.8 \pm 0.9) \times 10^{-5}$		–
$K^- 2\pi^- 2\pi^+ \pi^0 \nu_\tau$ (ex.K^0)	[g]	$(1.1 \pm 0.6) \times 10^{-6}$		657
$K^+ 3\pi^- \pi^+ \pi^0 \nu_\tau$		$< 8 \times 10^{-7}$	CL=90%	657
$3h^- 2h^+ 2\pi^0 \nu_\tau$		$< 3.4 \times 10^{-6}$	CL=90%	687
Miscellaneous other allowed modes				
$(5\pi)^- \nu_\tau$		$(7.8 \pm 0.5) \times 10^{-3}$		800
$4h^- 3h^+ \geq 0$ neutrals ν_τ ("7-prong")		$< 3.0 \times 10^{-7}$	CL=90%	682
$4h^- 3h^+ \nu_\tau$		$< 4.3 \times 10^{-7}$	CL=90%	682
$4h^- 3h^+ \pi^0 \nu_\tau$		$< 2.5 \times 10^{-7}$	CL=90%	612
$X^- (S=-1) \nu_\tau$		(2.92 ± 0.04) %		–
$K^*(892)^- \geq 0$ neutrals $\geq 0 K^0_L \nu_\tau$		(1.42 ± 0.18) %	S=1.4	665
$K^*(892)^- \nu_\tau$		(1.20 ± 0.07) %	S=1.8	665
$K^*(892)^- \nu_\tau \to \pi^- \overline{K}^0 \nu_\tau$		$(7.82 \pm 0.26) \times 10^{-3}$		–
$K^*(892)^0 K^- \geq 0$ neutrals ν_τ		$(3.2 \pm 1.4) \times 10^{-3}$		542
$K^*(892)^0 K^- \nu_\tau$		$(2.1 \pm 0.4) \times 10^{-3}$		542
$\overline{K}^*(892)^0 \pi^- \geq 0$ neutrals ν_τ		$(3.8 \pm 1.7) \times 10^{-3}$		655
$\overline{K}^*(892)^0 \pi^- \nu_\tau$		$(2.2 \pm 0.5) \times 10^{-3}$		655
$(\overline{K}^*(892)\pi)^- \nu_\tau \to \pi^- \overline{K}^0 \pi^0 \nu_\tau$		$(1.0 \pm 0.4) \times 10^{-3}$		–
$K_1(1270)^- \nu_\tau$		$(4.7 \pm 1.1) \times 10^{-3}$		447
$K_1(1400)^- \nu_\tau$		$(1.7 \pm 2.6) \times 10^{-3}$	S=1.7	335
$K^*(1410)^- \nu_\tau$		$(1.5 {}^{+1.4}_{-1.0}) \times 10^{-3}$		326
$K^*_0(1430)^- \nu_\tau$		$< 5 \times 10^{-4}$	CL=95%	317
$K^*_2(1430)^- \nu_\tau$		$< 3 \times 10^{-3}$	CL=95%	315
$\eta \pi^- \nu_\tau$		$< 9.9 \times 10^{-5}$	CL=95%	797
$\eta \pi^- \pi^0 \nu_\tau$	[g]	$(1.39 \pm 0.07) \times 10^{-3}$		778

$\eta\pi^-\pi^0\pi^0\nu_\tau$	[g]	(2.0 ± 0.4) × 10^{-4}		746
$\eta K^-\nu_\tau$	[g]	(1.55 ± 0.08) × 10^{-4}		719
$\eta K^*(892)^-\nu_\tau$		(1.38 ± 0.15) × 10^{-4}		511
$\eta K^-\pi^0\nu_\tau$	[g]	(4.8 ± 1.2) × 10^{-5}		665
$\eta K^-\pi^0$(non-$K^*(892)$)ν_τ		< 3.5 × 10^{-5}	CL=90%	–
$\eta\overline{K}^0\pi^-\nu_\tau$	[g]	(9.4 ± 1.5) × 10^{-5}		661
$\eta\overline{K}^0\pi^-\pi^0\nu_\tau$		< 5.0 × 10^{-5}	CL=90%	590
$\eta K^-K^0\nu_\tau$		< 9.0 × 10^{-6}	CL=90%	430
$\eta\pi^+\pi^-\pi^-\geq 0$ neutrals ν_τ		< 3 × 10^{-3}	CL=90%	744
$\eta\pi^-\pi^+\pi^-\nu_\tau$(ex.$K^0$)	[g]	(2.20 ± 0.13) × 10^{-4}		744
$\eta\pi^-\pi^+\pi^-\nu_\tau$(ex.$K^0$,$f_1(1285)$)		(9.9 ± 1.6) × 10^{-5}		–
$\eta a_1(1260)^-\nu_\tau \to \eta\pi^-\rho^0\nu_\tau$		< 3.9 × 10^{-4}	CL=90%	–
$\eta\eta\pi^-\nu_\tau$		< 7.4 × 10^{-6}	CL=90%	637
$\eta\eta\pi^-\pi^0\nu_\tau$		< 2.0 × 10^{-4}	CL=95%	559
$\eta\eta K^-\nu_\tau$		< 3.0 × 10^{-6}	CL=90%	382
$\eta'(958)\pi^-\nu_\tau$		< 4.0 × 10^{-6}	CL=90%	620
$\eta'(958)\pi^-\pi^0\nu_\tau$		< 1.2 × 10^{-5}	CL=90%	591
$\eta'(958)K^-\nu_\tau$		< 2.4 × 10^{-6}	CL=90%	495
$\phi\pi^-\nu_\tau$		(3.4 ± 0.6) × 10^{-5}		585
$\phi K^-\nu_\tau$	[g]	(4.4 ± 1.6) × 10^{-5}		445
$f_1(1285)\pi^-\nu_\tau$		(3.9 ± 0.5) × 10^{-4}	S=1.9	408
$f_1(1285)\pi^-\nu_\tau \to \eta\pi^-\pi^+\pi^-\nu_\tau$		(1.18 ± 0.07) × 10^{-4}	S=1.3	–
$f_1(1285)\pi^-\nu_\tau \to 3\pi^-2\pi^+\nu_\tau$	[g]	(5.2 ± 0.4) × 10^{-5}		–
$\pi(1300)^-\nu_\tau \to (\rho\pi)^-\nu_\tau \to (3\pi)^-\nu_\tau$		< 1.0 × 10^{-4}	CL=90%	–
$\pi(1300)^-\nu_\tau \to ((\pi\pi)_{S-\text{wave}}\pi)^-\nu_\tau \to (3\pi)^-\nu_\tau$		< 1.9 × 10^{-4}	CL=90%	–
$h^-\omega\geq 0$ neutrals ν_τ		(2.40 ± 0.08) %		708
$h^-\omega\nu_\tau$		(1.99 ± 0.06) %		708
$\pi^-\omega\nu_\tau$	[g]	(1.95 ± 0.06) %		708
$K^-\omega\nu_\tau$	[g]	(4.1 ± 0.9) × 10^{-4}		610
$h^-\omega\pi^0\nu_\tau$	[g]	(4.1 ± 0.4) × 10^{-3}		684
$h^-\omega 2\pi^0\nu_\tau$		(1.4 ± 0.5) × 10^{-4}		644
$\pi^-\omega 2\pi^0\nu_\tau$	[g]	(7.2 ± 1.6) × 10^{-5}		644
$h^-2\omega\nu_\tau$		< 5.4 × 10^{-7}	CL=90%	250
$2h^-h^+\omega\nu_\tau$		(1.20 ± 0.22) × 10^{-4}		641
$2\pi^-\pi^+\omega\nu_\tau$(ex.$K^0$)	[g]	(8.4 ± 0.6) × 10^{-5}		641

Lepton Family number (*LF*), Lepton number (*L*), or Baryon number (*B*) violating modes

L means lepton number violation (*e.g.* $\tau^-\to e^+\pi^-\pi^-$). Following common usage, *LF* means lepton family violation *and not* lepton number violation (*e.g.* $\tau^-\to e^-\pi^+\pi^-$). *B* means baryon number violation.

$e^-\gamma$	LF	< 3.3 × 10^{-8}	CL=90%	888
$\mu^-\gamma$	LF	< 4.4 × 10^{-8}	CL=90%	885
$e^-\pi^0$	LF	< 8.0 × 10^{-8}	CL=90%	883
$\mu^-\pi^0$	LF	< 1.1 × 10^{-7}	CL=90%	880
$e^-K^0_S$	LF	< 2.6 × 10^{-8}	CL=90%	819
$\mu^-K^0_S$	LF	< 2.3 × 10^{-8}	CL=90%	815
$e^-\eta$	LF	< 9.2 × 10^{-8}	CL=90%	804
$\mu^-\eta$	LF	< 6.5 × 10^{-8}	CL=90%	800
$e^-\rho^0$	LF	< 1.8 × 10^{-8}	CL=90%	719
$\mu^-\rho^0$	LF	< 1.2 × 10^{-8}	CL=90%	715

$e^- \omega$	*LF*	$<$	4.8	$\times 10^{-8}$	CL=90%	716
$\mu^- \omega$	*LF*	$<$	4.7	$\times 10^{-8}$	CL=90%	711
$e^- K^*(892)^0$	*LF*	$<$	3.2	$\times 10^{-8}$	CL=90%	665
$\mu^- K^*(892)^0$	*LF*	$<$	5.9	$\times 10^{-8}$	CL=90%	659
$e^- \overline{K}^*(892)^0$	*LF*	$<$	3.4	$\times 10^{-8}$	CL=90%	665
$\mu^- \overline{K}^*(892)^0$	*LF*	$<$	7.0	$\times 10^{-8}$	CL=90%	659
$e^- \eta'(958)$	*LF*	$<$	1.6	$\times 10^{-7}$	CL=90%	630
$\mu^- \eta'(958)$	*LF*	$<$	1.3	$\times 10^{-7}$	CL=90%	625
$e^- f_0(980) \rightarrow e^- \pi^+ \pi^-$	*LF*	$<$	3.2	$\times 10^{-8}$	CL=90%	–
$\mu^- f_0(980) \rightarrow \mu^- \pi^+ \pi^-$	*LF*	$<$	3.4	$\times 10^{-8}$	CL=90%	–
$e^- \phi$	*LF*	$<$	3.1	$\times 10^{-8}$	CL=90%	596
$\mu^- \phi$	*LF*	$<$	8.4	$\times 10^{-8}$	CL=90%	590
$e^- e^+ e^-$	*LF*	$<$	2.7	$\times 10^{-8}$	CL=90%	888
$e^- \mu^+ \mu^-$	*LF*	$<$	2.7	$\times 10^{-8}$	CL=90%	882
$e^+ \mu^- \mu^-$	*LF*	$<$	1.7	$\times 10^{-8}$	CL=90%	882
$\mu^- e^+ e^-$	*LF*	$<$	1.8	$\times 10^{-8}$	CL=90%	885
$\mu^+ e^- e^-$	*LF*	$<$	1.5	$\times 10^{-8}$	CL=90%	885
$\mu^- \mu^+ \mu^-$	*LF*	$<$	2.1	$\times 10^{-8}$	CL=90%	873
$e^- \pi^+ \pi^-$	*LF*	$<$	2.3	$\times 10^{-8}$	CL=90%	877
$e^+ \pi^- \pi^-$	*L*	$<$	2.0	$\times 10^{-8}$	CL=90%	877
$\mu^- \pi^+ \pi^-$	*LF*	$<$	2.1	$\times 10^{-8}$	CL=90%	866
$\mu^+ \pi^- \pi^-$	*L*	$<$	3.9	$\times 10^{-8}$	CL=90%	866
$e^- \pi^+ K^-$	*LF*	$<$	3.7	$\times 10^{-8}$	CL=90%	813
$e^- \pi^- K^+$	*LF*	$<$	3.1	$\times 10^{-8}$	CL=90%	813
$e^+ \pi^- K^-$	*L*	$<$	3.2	$\times 10^{-8}$	CL=90%	813
$e^- K^0_S K^0_S$	*LF*	$<$	7.1	$\times 10^{-8}$	CL=90%	736
$e^- K^+ K^-$	*LF*	$<$	3.4	$\times 10^{-8}$	CL=90%	738
$e^+ K^- K^-$	*L*	$<$	3.3	$\times 10^{-8}$	CL=90%	738
$\mu^- \pi^+ K^-$	*LF*	$<$	8.6	$\times 10^{-8}$	CL=90%	800
$\mu^- \pi^- K^+$	*LF*	$<$	4.5	$\times 10^{-8}$	CL=90%	800
$\mu^+ \pi^- K^-$	*L*	$<$	4.8	$\times 10^{-8}$	CL=90%	800
$\mu^- K^0_S K^0_S$	*LF*	$<$	8.0	$\times 10^{-8}$	CL=90%	696
$\mu^- K^+ K^-$	*LF*	$<$	4.4	$\times 10^{-8}$	CL=90%	699
$\mu^+ K^- K^-$	*L*	$<$	4.7	$\times 10^{-8}$	CL=90%	699
$e^- \pi^0 \pi^0$	*LF*	$<$	6.5	$\times 10^{-6}$	CL=90%	878
$\mu^- \pi^0 \pi^0$	*LF*	$<$	1.4	$\times 10^{-5}$	CL=90%	867
$e^- \eta\eta$	*LF*	$<$	3.5	$\times 10^{-5}$	CL=90%	699
$\mu^- \eta\eta$	*LF*	$<$	6.0	$\times 10^{-5}$	CL=90%	653
$e^- \pi^0 \eta$	*LF*	$<$	2.4	$\times 10^{-5}$	CL=90%	798
$\mu^- \pi^0 \eta$	*LF*	$<$	2.2	$\times 10^{-5}$	CL=90%	784
$p \mu^- \mu^-$	*L,B*	$<$	4.4	$\times 10^{-7}$	CL=90%	618
$\overline{p} \mu^+ \mu^-$	*L,B*	$<$	3.3	$\times 10^{-7}$	CL=90%	618
$\overline{p} \gamma$	*L,B*	$<$	3.5	$\times 10^{-6}$	CL=90%	641
$\overline{p} \pi^0$	*L,B*	$<$	1.5	$\times 10^{-5}$	CL=90%	632
$\overline{p} 2\pi^0$	*L,B*	$<$	3.3	$\times 10^{-5}$	CL=90%	604
$\overline{p} \eta$	*L,B*	$<$	8.9	$\times 10^{-6}$	CL=90%	475
$\overline{p} \pi^0 \eta$	*L,B*	$<$	2.7	$\times 10^{-5}$	CL=90%	360
$\Lambda \pi^-$	*L,B*	$<$	7.2	$\times 10^{-8}$	CL=90%	525
$\overline{\Lambda} \pi^-$	*L,B*	$<$	1.4	$\times 10^{-7}$	CL=90%	525
e^- light boson	*LF*	$<$	2.7	$\times 10^{-3}$	CL=95%	–
μ^- light boson	*LF*	$<$	5	$\times 10^{-3}$	CL=95%	–

Heavy Charged Lepton Searches

$L^{\pm}$ – charged lepton

Mass $m >$ 100.8 GeV, CL = 95% [h] Decay to νW.

$L^{\pm}$ – stable charged heavy lepton

Mass $m >$ 102.6 GeV, CL = 95%

Neutrino Properties

See the note on "Neutrino properties listings" in the Particle Listings.

Mass $m <$ 1.1 eV, CL = 90% (tritium decay)
Mean life/mass, $\tau/m >$ 300 s/eV, CL = 90% (reactor)
Mean life/mass, $\tau/m >$ 7×10^{9} s/eV (solar)
Mean life/mass, $\tau/m >$ 15.4 s/eV, CL = 90% (accelerator)
Magnetic moment μ < 0.28×10^{-10} μ_B, CL = 90% (solar + radiochemical)

Number of Neutrino Types

Number $N = 2.996 \pm 0.007$ (Standard Model fits to LEP-SLC data)
Number $N = 2.92 \pm 0.05$ (S = 1.2) (Direct measurement of invisible Z width)

Neutrino Mixing

The following values are obtained through data analyses based on the 3-neutrino mixing scheme described in the review "Neutrino Masses, Mixing, and Oscillations."

$\sin^2(\theta_{12}) = 0.307 \pm 0.013$
$\Delta m^2_{21} = (7.53 \pm 0.18) \times 10^{-5}$ eV^2
$\sin^2(\theta_{23}) = 0.547 \pm 0.021$ (Inverted order)
$\sin^2(\theta_{23}) = 0.545 \pm 0.021$ (Normal order)
$\Delta m^2_{32} = (-2.546^{+0.034}_{-0.040}) \times 10^{-3}$ eV^2 (Inverted order)
$\Delta m^2_{32} = (2.453 \pm 0.034) \times 10^{-3}$ eV^2 (Normal order)
$\sin^2(\theta_{13}) = (2.18 \pm 0.07) \times 10^{-2}$
δ, CP violating phase $= 1.36 \pm 0.17\ \pi$ rad
$\langle \Delta m^2_{21} - \Delta \overline{m}^2_{21} \rangle < 1.1 \times 10^{-4}$ eV^2, CL = 99.7%
$\langle \Delta m^2_{32} - \Delta \overline{m}^2_{32} \rangle = (-0.12 \pm 0.25) \times 10^{-3}$ eV^2

NOTES

In this Summary Table:

When a quantity has "(S = ...)" to its right, the error on the quantity has been enlarged by the "scale factor" S, defined as S = $\sqrt{\chi^2/(N-1)}$, where N is the number of measurements used in calculating the quantity.

A decay momentum p is given for each decay mode. For a 2-body decay, p is the momentum of each decay product in the rest frame of the decaying particle. For a 3-or-more-body decay, p is the largest momentum any of the products can have in this frame.

[*a*] This is the best limit for the mode $e^- \rightarrow \nu\gamma$. The best limit for Nuclear de-excitation experiments is 6.4×10^{24} yr.

[*b*] See the review on "Muon Decay Parameters" for definitions and details.

[*c*] P_μ is the longitudinal polarization of the muon from pion decay. For $V{-}A$ coupling, $P_\mu = 1$ and $\rho = \delta = 3/4$.

[*d*] This only includes events with energy of $e > 45$ MeV and energy of $\gamma > 40$ MeV. Since the $e^- \overline{\nu}_e \nu_\mu$ and $e^- \overline{\nu}_e \nu_\mu \gamma$ modes cannot be clearly separated, we regard the latter mode as a subset of the former.

[*e*] See the relevant Particle Listings in the Full *Review of Particle Physics* for the energy limits used in this measurement.

[*f*] A test of additive vs. multiplicative lepton family number conservation.

[*g*] Basis mode for the τ.

[*h*] $L^\pm$ mass limit depends on decay assumptions; see the Full Listings.

QUARKS

The u-, d-, and s-quark masses are estimates of so-called "current-quark masses," in a mass-independent subtraction scheme such as $\overline{\text{MS}}$ at a scale $\mu \approx 2$ GeV. The c- and b-quark masses are the "running" masses in the $\overline{\text{MS}}$ scheme. This can be different from the heavy quark masses obtained in potential models.

u

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

$m_u = 2.16^{+0.49}_{-0.26}$ MeV Charge $= \frac{2}{3}\ e$ $I_z = +\frac{1}{2}$

$m_u/m_d = 0.47^{+0.06}_{-0.07}$

d

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

$m_d = 4.67^{+0.48}_{-0.17}$ MeV Charge $= -\frac{1}{3}\ e$ $I_z = -\frac{1}{2}$

$m_s/m_d = 17–22$

$\overline{m} = (m_u+m_d)/2 = 3.45^{+0.55}_{-0.15}$ MeV

s

$I(J^P) = 0(\frac{1}{2}^+)$

$m_s = 93^{+11}_{-\ 5}$ MeV Charge $= -\frac{1}{3}\ e$ Strangeness $= -1$

$m_s\ /\ ((m_u + m_d)/2) = 27.3^{+0.7}_{-1.3}$

c

$I(J^P) = 0(\frac{1}{2}^+)$

$m_c = 1.27 \pm 0.02$ GeV Charge $= \frac{2}{3}\ e$ Charm $= +1$

$m_c/m_s = 11.72 \pm 0.25$

$m_b/m_c = 4.577 \pm 0.008$

$m_b - m_c = 3.45 \pm 0.05$ GeV

b

$I(J^P) = 0(\frac{1}{2}^+)$

$m_b = 4.18^{+0.03}_{-0.02}$ GeV Charge $= -\frac{1}{3}\ e$ Bottom $= -1$

t

$I(J^P) = 0(\frac{1}{2}^+)$

Charge $= \frac{2}{3}\ e$ Top $= +1$

Mass (direct measurements) $m = 172.76 \pm 0.30$ GeV [a,b] (S = 1.2)

Mass (from cross-section measurements) $m = 162.5^{+2.1}_{-1.5}$ GeV [a]

Mass (Pole from cross-section measurements) $m = 172.4 \pm 0.7$ GeV

$m_t - m_{\overline{t}} = -0.16 \pm 0.19$ GeV

Full width $\Gamma = 1.42^{+0.19}_{-0.15}$ GeV (S = 1.4)

$\Gamma\big(W b\big)/\Gamma\big(W q(q = b,\ s,\ d)\big) = 0.957 \pm 0.034$ (S = 1.5)

t-quark EW Couplings

$F_0 = 0.687 \pm 0.018$
$F_- = 0.320 \pm 0.013$
$F_+ = 0.002 \pm 0.011$
$F_{V+A} < 0.29$, CL = 95%

t DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$W q (q = b, s, d)$				–
$W b$				–
$e \nu_e b$		(11.10 ± 0.30) %		–
$\mu \nu_\mu b$		(11.40 ± 0.20) %		–
$\tau \nu_\tau b$		(11.1 ± 0.9) %		–
$q \overline{q} b$		(66.5 ± 1.4) %		–
$\gamma q (q{=}u,c)$		[c] $< 1.8 \times 10^{-4}$	95%	–
$\Delta T = 1$ weak neutral current (*T1*) modes				
$Z q (q{=}u,c)$	*T1*	[d] $< 5 \times 10^{-4}$	95%	–
$H u$	*T1*	$< 1.2 \times 10^{-3}$	95%	–
$H c$	*T1*	$< 1.1 \times 10^{-3}$	95%	–
$\ell^+ \overline{q} \overline{q}' (q{=}d,s,b;\ q'{=}u,c)$	*T1*	$< 1.6 \times 10^{-3}$	95%	–

b′ (4th Generation) Quark, Searches for

Mass $m >$ 190 GeV, CL = 95% ($p\overline{p}$, quasi-stable b')
Mass $m >$ 1130 GeV, CL = 95% ($B(b' \to Z b) = 1$)
Mass $m >$ 1350 GeV, CL = 95% ($B(b' \to W t) = 1$)
Mass $m >$ 46.0 GeV, CL = 95% ($e^+ e^-$, all decays)

t′ (4th Generation) Quark, Searches for

$m(t'(2/3)) >$ 1280 GeV, CL = 95% ($B(t' \to Z t) = 1$)
$m(t'(2/3)) >$ 1295 GeV, CL = 95% ($B(t' \to W b) = 1$)
$m(t'(2/3)) >$ 1310 GeV, CL = 95% (singlet t')
$m(t'(5/3)) >$ 1350 GeV, CL = 95%

Free Quark Searches

All searches since 1977 have had negative results.

NOTES

[a] A discussion of the definition of the top quark mass in these measurements can be found in the review "The Top Quark."

[b] Based on published top mass measurements using data from Tevatron Run-I and Run-II and LHC at $\sqrt{s} = 7$ TeV. Including the most recent unpublished results from Tevatron Run-II, the Tevatron Electroweak Working Group reports a top mass of 173.2 ± 0.9 GeV. See the note "The Top Quark' in the Quark Particle Listings of this *Review*.

[c] This limit is for $\Gamma(t \to \gamma q)/\Gamma(t \to W b)$.

[d] This limit is for $\Gamma(t \to Z q)/\Gamma(t \to W b)$.

LIGHT UNFLAVORED MESONS ($S = C = B = 0$)

For $I = 1$ (π, b, ρ, a): $u\overline{d}$, $(u\overline{u}-d\overline{d})/\sqrt{2}$, $d\overline{u}$;
for $I = 0$ (η, η', h, h', ω, ϕ, f, f'): $c_1(u\overline{u} + d\overline{d}) + c_2(s\overline{s})$

$\pi^{\pm}$

$I^G(J^P) = 1^-(0^-)$

Mass $m = 139.57039 \pm 0.00018$ MeV (S = 1.8)
Mean life $\tau = (2.6033 \pm 0.0005) \times 10^{-8}$ s (S = 1.2)
$c\tau = 7.8045$ m

$\pi^{\pm} \to \ell^{\pm}\nu\gamma$ form factors [a]

$F_V = 0.0254 \pm 0.0017$
$F_A = 0.0119 \pm 0.0001$
F_V slope parameter $a = 0.10 \pm 0.06$
$R = 0.059^{+0.009}_{-0.008}$

π^- modes are charge conjugates of the modes below.

For decay limits to particles which are not established, see the section on Searches for Axions and Other Very Light Bosons.

π^+ DECAY MODES			Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\mu^+\nu_\mu$		[b]	(99.98770 ± 0.00004) %		30
$\mu^+\nu_\mu\gamma$		[c]	$(2.00 \pm 0.25) \times 10^{-4}$		30
$e^+\nu_e$		[b]	$(1.230 \pm 0.004) \times 10^{-4}$		70
$e^+\nu_e\gamma$		[c]	$(7.39 \pm 0.05) \times 10^{-7}$		70
$e^+\nu_e\pi^0$			$(1.036 \pm 0.006) \times 10^{-8}$		4
$e^+\nu_e e^+ e^-$			$(3.2 \pm 0.5) \times 10^{-9}$		70
$e^+\nu_e\nu\overline{\nu}$			$< 5 \times 10^{-6}$	90%	70
Lepton Family number (*LF*) or Lepton number (*L*) violating modes					
$\mu^+\overline{\nu}_e$	*L*	[d]	$< 1.5 \times 10^{-3}$	90%	30
$\mu^+\nu_e$	*LF*	[d]	$< 8.0 \times 10^{-3}$	90%	30
$\mu^- e^+ e^+ \nu$	*LF*		$< 1.6 \times 10^{-6}$	90%	30

π^0

$I^G(J^{PC}) = 1^-(0^{-+})$

Mass $m = 134.9768 \pm 0.0005$ MeV (S = 1.1)
$m_{\pi^\pm} - m_{\pi^0} = 4.5936 \pm 0.0005$ MeV
Mean life $\tau = (8.52 \pm 0.18) \times 10^{-17}$ s (S = 1.2)
$c\tau = 25.5$ nm

For decay limits to particles which are not established, see the appropriate Search sections (A^0 (axion) and Other Light Boson (X^0) Searches, etc.).

π^0 DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
2γ	(98.823 ± 0.034) %	S=1.5	67
$e^+e^-\gamma$	(1.174 ± 0.035) %	S=1.5	67
γ positronium	$(1.82 \pm 0.29) \times 10^{-9}$		67
$e^+e^+e^-e^-$	$(3.34 \pm 0.16) \times 10^{-5}$		67

$e^+ e^-$			$(6.46 \pm 0.33) \times 10^{-8}$		67
4γ		$<$	2×10^{-8}	CL=90%	67
$\nu \overline{\nu}$		[e] $<$	2.7×10^{-7}	CL=90%	67
$\nu_e \overline{\nu}_e$		$<$	1.7×10^{-6}	CL=90%	67
$\nu_\mu \overline{\nu}_\mu$		$<$	1.6×10^{-6}	CL=90%	67
$\nu_\tau \overline{\nu}_\tau$		$<$	2.1×10^{-6}	CL=90%	67
$\gamma \nu \overline{\nu}$		$<$	1.9×10^{-7}	CL=90%	67
Charge conjugation (C) or Lepton Family number (LF) violating modes					
3γ	C	$<$	3.1×10^{-8}	CL=90%	67
$\mu^+ e^-$	LF	$<$	3.8×10^{-10}	CL=90%	26
$\mu^- e^+$	LF	$<$	3.4×10^{-9}	CL=90%	26
$\mu^+ e^- + \mu^- e^+$	LF	$<$	3.6×10^{-10}	CL=90%	26

η

$I^G(J^{PC}) = 0^+(0^{-+})$

Mass $m = 547.862 \pm 0.017$ MeV

Full width $\Gamma = 1.31 \pm 0.05$ keV

C-nonconserving decay parameters

$\pi^+ \pi^- \pi^0$ left-right asymmetry $= (0.09^{+0.11}_{-0.12}) \times 10^{-2}$

$\pi^+ \pi^- \pi^0$ sextant asymmetry $= (0.12^{+0.10}_{-0.11}) \times 10^{-2}$

$\pi^+ \pi^- \pi^0$ quadrant asymmetry $= (-0.09 \pm 0.09) \times 10^{-2}$

$\pi^+ \pi^- \gamma$ left-right asymmetry $= (0.9 \pm 0.4) \times 10^{-2}$

$\pi^+ \pi^- \gamma$ β (D-wave) $= -0.02 \pm 0.07$ (S = 1.3)

CP-nonconserving decay parameters

$\pi^+ \pi^- e^+ e^-$ decay-plane asymmetry $A_\phi = (-0.6 \pm 3.1) \times 10^{-2}$

Other decay parameters

$\pi^0 \pi^0 \pi^0$ Dalitz plot $\alpha = -0.0288 \pm 0.0012$ (S = 1.1)

Parameter Λ in $\eta \to \ell^+ \ell^- \gamma$ decay $= 0.716 \pm 0.011$ GeV/c^2

η DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Neutral modes			
neutral modes	(72.12 ± 0.34) %	S=1.2	–
2γ	(39.41 ± 0.20) %	S=1.1	274
$3\pi^0$	(32.68 ± 0.23) %	S=1.1	179
$\pi^0 2\gamma$	$(2.56 \pm 0.22) \times 10^{-4}$		257
$2\pi^0 2\gamma$	$< 1.2 \times 10^{-3}$	CL=90%	238
4γ	$< 2.8 \times 10^{-4}$	CL=90%	274
invisible	$< 1.0 \times 10^{-4}$	CL=90%	–
Charged modes			
charged modes	(27.89 ± 0.29) %	S=1.2	–
$\pi^+ \pi^- \pi^0$	(22.92 ± 0.28) %	S=1.2	174
$\pi^+ \pi^- \gamma$	(4.22 ± 0.08) %	S=1.1	236
$e^+ e^- \gamma$	$(6.9 \pm 0.4) \times 10^{-3}$	S=1.3	274
$\mu^+ \mu^- \gamma$	$(3.1 \pm 0.4) \times 10^{-4}$		253
$e^+ e^-$	$< 7 \times 10^{-7}$	CL=90%	274
$\mu^+ \mu^-$	$(5.8 \pm 0.8) \times 10^{-6}$		253
$2e^+ 2e^-$	$(2.40 \pm 0.22) \times 10^{-5}$		274
$\pi^+ \pi^- e^+ e^- (\gamma)$	$(2.68 \pm 0.11) \times 10^{-4}$		235
$e^+ e^- \mu^+ \mu^-$	$< 1.6 \times 10^{-4}$	CL=90%	253
$2\mu^+ 2\mu^-$	$< 3.6 \times 10^{-4}$	CL=90%	161
$\mu^+ \mu^- \pi^+ \pi^-$	$< 3.6 \times 10^{-4}$	CL=90%	113

$\pi^+ e^- \overline{\nu}_e$ + c.c.			< 1.7	$\times 10^{-4}$	CL=90%	256
$\pi^+ \pi^- 2\gamma$			< 2.1	$\times 10^{-3}$		236
$\pi^+ \pi^- \pi^0 \gamma$			< 5	$\times 10^{-4}$	CL=90%	174
$\pi^0 \mu^+ \mu^- \gamma$			< 3	$\times 10^{-6}$	CL=90%	210

Charge conjugation (C), Parity (P), Charge conjugation × Parity (CP), or Lepton Family number (LF) violating modes

$\pi^0 \gamma$	C	[f]	< 9	$\times 10^{-5}$	CL=90%	257
$\pi^+ \pi^-$	P,CP		< 1.3	$\times 10^{-5}$	CL=90%	236
$2\pi^0$	P,CP		< 3.5	$\times 10^{-4}$	CL=90%	238
$2\pi^0 \gamma$	C		< 5	$\times 10^{-4}$	CL=90%	238
$3\pi^0 \gamma$	C		< 6	$\times 10^{-5}$	CL=90%	179
3γ	C		< 1.6	$\times 10^{-5}$	CL=90%	274
$4\pi^0$	P,CP		< 6.9	$\times 10^{-7}$	CL=90%	40
$\pi^0 e^+ e^-$	C	[g]	< 8	$\times 10^{-6}$	CL=90%	257
$\pi^0 \mu^+ \mu^-$	C	[g]	< 5	$\times 10^{-6}$	CL=90%	210
$\mu^+ e^-$ + $\mu^- e^+$	LF		< 6	$\times 10^{-6}$	CL=90%	264

$f_0(500)$

$I^G(J^{PC}) = 0^+(0^{++})$

also known as σ; was $f_0(600)$

See the review on "Scalar Mesons below 2 GeV."

Mass (T-Matrix Pole $\sqrt{s}$) = (400–550)$-i$(200–350) MeV

Mass (Breit-Wigner) = (400–550) MeV

Full width (Breit-Wigner) = (400–700) MeV

$\rho(770)$

$I^G(J^{PC}) = 1^+(1^{--})$

See the note in $\rho(770)$ Particle Listings.

Mass m = 775.26 ± 0.25 MeV

Full width Γ = 149.1 ± 0.8 MeV

Γ_{ee} = 7.04 ± 0.06 keV

ρ(770) DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\pi\pi$		~ 100 %		363
$\rho(770)^{\pm}$ decays				
$\pi^{\pm} \gamma$		(4.5 ±0.5) $\times 10^{-4}$	S=2.2	375
$\pi^{\pm} \eta$		< 6 $\times 10^{-3}$	CL=84%	152
$\pi^{\pm} \pi^+ \pi^- \pi^0$		< 2.0 $\times 10^{-3}$	CL=84%	254
$\rho(770)^0$ decays				
$\pi^+ \pi^- \gamma$		(9.9 ±1.6) $\times 10^{-3}$		362
$\pi^0 \gamma$		(4.7 ±0.6) $\times 10^{-4}$	S=1.4	376
$\eta \gamma$		(3.00±0.21) $\times 10^{-4}$		194
$\pi^0 \pi^0 \gamma$		(4.5 ±0.8) $\times 10^{-5}$		363
$\mu^+ \mu^-$	[h]	(4.55±0.28) $\times 10^{-5}$		373
$e^+ e^-$	[h]	(4.72±0.05) $\times 10^{-5}$		388
$\pi^+ \pi^- \pi^0$		($1.01^{+0.54}_{-0.36}$ ±0.34) $\times 10^{-4}$		323
$\pi^+ \pi^- \pi^+ \pi^-$		(1.8 ±0.9) $\times 10^{-5}$		251
$\pi^+ \pi^- \pi^0 \pi^0$		(1.6 ±0.8) $\times 10^{-5}$		257
$\pi^0 e^+ e^-$		< 1.2 $\times 10^{-5}$	CL=90%	376

$\omega(782)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 782.65 \pm 0.12$ MeV (S = 1.9)
Full width $\Gamma = 8.49 \pm 0.08$ MeV
$\Gamma_{ee} = 0.60 \pm 0.02$ keV

$\omega(782)$ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\pi^+\pi^-\pi^0$		(89.3 ± 0.6) %		327
$\pi^0\gamma$		(8.40 ± 0.22) %	S=1.8	380
$\pi^+\pi^-$		(1.53 ± 0.06) %		366
neutrals (excluding $\pi^0\gamma$)		$(7 {}^{+7}_{-4}) \times 10^{-3}$	S=1.1	–
$\eta\gamma$		$(4.5 \pm 0.4) \times 10^{-4}$	S=1.1	200
$\pi^0 e^+ e^-$		$(7.7 \pm 0.6) \times 10^{-4}$		380
$\pi^0 \mu^+ \mu^-$		$(1.34 \pm 0.18) \times 10^{-4}$	S=1.5	349
$e^+ e^-$		$(7.36 \pm 0.15) \times 10^{-5}$	S=1.5	391
$\pi^+\pi^-\pi^0\pi^0$		$< 2 \times 10^{-4}$	CL=90%	262
$\pi^+\pi^-\gamma$		$< 3.6 \times 10^{-3}$	CL=95%	366
$\pi^+\pi^-\pi^+\pi^-$		$< 1 \times 10^{-3}$	CL=90%	256
$\pi^0\pi^0\gamma$		$(6.7 \pm 1.1) \times 10^{-5}$		367
$\eta\pi^0\gamma$		$< 3.3 \times 10^{-5}$	CL=90%	162
$\mu^+\mu^-$		$(7.4 \pm 1.8) \times 10^{-5}$		377
3γ		$< 1.9 \times 10^{-4}$	CL=95%	391
Charge conjugation (C) violating modes				
$\eta\pi^0$	C	$< 2.2 \times 10^{-4}$	CL=90%	162
$2\pi^0$	C	$< 2.2 \times 10^{-4}$	CL=90%	367
$3\pi^0$	C	$< 2.3 \times 10^{-4}$	CL=90%	330
invisible		$< 7 \times 10^{-5}$	CL=90%	–

$\eta'(958)$

$I^G(J^{PC}) = 0^+(0^{-+})$

Mass $m = 957.78 \pm 0.06$ MeV
Full width $\Gamma = 0.188 \pm 0.006$ MeV

$\eta'(958)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\pi^+\pi^-\eta$	(42.5 ± 0.5) %		232
$\rho^0\gamma$ (including non-resonant $\pi^+\pi^-\gamma$)	(29.5 ± 0.4) %		165
$\pi^0\pi^0\eta$	(22.4 ± 0.5) %		239
$\omega\gamma$	(2.52 ± 0.07) %		159
$\omega e^+ e^-$	$(2.0 \pm 0.4) \times 10^{-4}$		159
$\gamma\gamma$	(2.307 ± 0.033) %		479
$3\pi^0$	$(2.50 \pm 0.17) \times 10^{-3}$		430
$\mu^+\mu^-\gamma$	$(1.13 \pm 0.28) \times 10^{-4}$		467
$\pi^+\pi^-\mu^+\mu^-$	$< 2.9 \times 10^{-5}$	90%	401
$\pi^+\pi^-\pi^0$	$(3.61 \pm 0.17) \times 10^{-3}$		428
$(\pi^+\pi^-\pi^0)$ S-wave	$(3.8 \pm 0.5) \times 10^{-3}$		428
$\pi^\mp\rho^\pm$	$(7.4 \pm 2.3) \times 10^{-4}$		106
$\pi^0\rho^0$	< 4 %	90%	111
$2(\pi^+\pi^-)$	$(8.4 \pm 0.9) \times 10^{-5}$		372
$\pi^+\pi^- 2\pi^0$	$(1.8 \pm 0.4) \times 10^{-4}$		376
$2(\pi^+\pi^-)$ neutrals	< 1 %	95%	–
$2(\pi^+\pi^-)\pi^0$	$< 1.8 \times 10^{-3}$	90%	298

$2(\pi^+\pi^-)2\pi^0$			$<$ 1 %		95%	197
$3(\pi^+\pi^-)$			$<$ 3.1 $\times 10^{-5}$		90%	189
$K^\pm\pi^\mp$			$<$ 4 $\times 10^{-5}$		90%	334
$\pi^+\pi^-e^+e^-$			$(2.4\ ^{+1.3}_{-1.0}) \times 10^{-3}$			458
$\pi^+e^-\nu_e$ + c.c.			$<$ 2.1 $\times 10^{-4}$		90%	469
γe^+e^-			$(4.91 \pm 0.27) \times 10^{-4}$			479
$\pi^0\gamma\gamma$			$(3.20 \pm 0.24) \times 10^{-3}$			469
$\pi^0\gamma\gamma$(non resonant)			$(6.2 \pm 0.9) \times 10^{-4}$			–
$\eta\gamma\gamma$			$<$ 1.33 $\times 10^{-4}$		90%	322
$4\pi^0$			$<$ 3.2 $\times 10^{-4}$		90%	380
e^+e^-			$<$ 5.6 $\times 10^{-9}$		90%	479
invisible			$<$ 6 $\times 10^{-4}$		90%	–

Charge conjugation (C), Parity (P), Lepton family number (LF) violating modes

$\pi^+\pi^-$	P,CP		$<$ 1.8 $\times 10^{-5}$	90%	458
$\pi^0\pi^0$	P,CP		$<$ 4 $\times 10^{-4}$	90%	459
$\pi^0e^+e^-$	C	[g]	$<$ 1.4 $\times 10^{-3}$	90%	469
ηe^+e^-	C	[g]	$<$ 2.4 $\times 10^{-3}$	90%	322
3γ	C		$<$ 1.0 $\times 10^{-4}$	90%	479
$\mu^+\mu^-\pi^0$	C	[g]	$<$ 6.0 $\times 10^{-5}$	90%	445
$\mu^+\mu^-\eta$	C	[g]	$<$ 1.5 $\times 10^{-5}$	90%	273
$e\mu$	LF		$<$ 4.7 $\times 10^{-4}$	90%	473

$f_0(980)$

$I^G(J^{PC}) = 0^+(0^{++})$

See the review on "Scalar Mesons below 2 GeV."

Mass $m = 990 \pm 20$ MeV

Full width $\Gamma = 10$ to 100 MeV

$a_0(980)$

$I^G(J^{PC}) = 1^-(0^{++})$

See the review on "Scalar Mesons below 2 GeV."

Mass $m = 980 \pm 20$ MeV

Full width $\Gamma = 50$ to 100 MeV

$\phi(1020)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 1019.461 \pm 0.016$ MeV

Full width $\Gamma = 4.249 \pm 0.013$ MeV (S = 1.1)

$\phi(1020)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
K^+K^-	(49.2 ± 0.5) %	S=1.3	127
$K^0_L K^0_S$	(34.0 ± 0.4) %	S=1.3	110
$\rho\pi + \pi^+\pi^-\pi^0$	(15.24 ± 0.33) %	S=1.2	–
$\eta\gamma$	(1.303 ± 0.025) %	S=1.2	363
$\pi^0\gamma$	$(1.30 \pm 0.05) \times 10^{-3}$		501
$\ell^+\ell^-$	—		510
e^+e^-	$(2.973 \pm 0.034) \times 10^{-4}$	S=1.3	510
$\mu^+\mu^-$	$(2.86 \pm 0.19) \times 10^{-4}$		499
ηe^+e^-	$(1.08 \pm 0.04) \times 10^{-4}$		363
$\pi^+\pi^-$	$(7.3 \pm 1.3) \times 10^{-5}$		490

$\omega\pi^0$		$(4.7 \pm 0.5) \times 10^{-5}$			172
$\omega\gamma$		< 5 %		CL=84%	209
$\rho\gamma$		$< 1.2 \times 10^{-5}$		CL=90%	215
$\pi^+\pi^-\gamma$		$(4.1 \pm 1.3) \times 10^{-5}$			490
$f_0(980)\gamma$		$(3.22 \pm 0.19) \times 10^{-4}$		S=1.1	29
$\pi^0\pi^0\gamma$		$(1.12 \pm 0.06) \times 10^{-4}$			492
$\pi^+\pi^-\pi^+\pi^-$		$(3.9 {}^{+2.8}_{-2.2}) \times 10^{-6}$			410
$\pi^+\pi^+\pi^-\pi^-\pi^0$		$< 4.6 \times 10^{-6}$		CL=90%	342
$\pi^0 e^+ e^-$		$(1.33 {}^{+0.07}_{-0.10}) \times 10^{-5}$			501
$\pi^0\eta\gamma$		$(7.27 \pm 0.30) \times 10^{-5}$		S=1.5	346
$a_0(980)\gamma$		$(7.6 \pm 0.6) \times 10^{-5}$			39
$K^0\overline{K}^0\gamma$		$< 1.9 \times 10^{-8}$		CL=90%	110
$\eta'(958)\gamma$		$(6.22 \pm 0.21) \times 10^{-5}$			60
$\eta\pi^0\pi^0\gamma$		$< 2 \times 10^{-5}$		CL=90%	293
$\mu^+\mu^-\gamma$		$(1.4 \pm 0.5) \times 10^{-5}$			499
$\rho\gamma\gamma$		$< 1.2 \times 10^{-4}$		CL=90%	215
$\eta\pi^+\pi^-$		$< 1.8 \times 10^{-5}$		CL=90%	288
$\eta\mu^+\mu^-$		$< 9.4 \times 10^{-6}$		CL=90%	321
$\eta U \to \eta e^+ e^-$		$< 1 \times 10^{-6}$		CL=90%	–
invisible		$< 1.7 \times 10^{-4}$		CL=90%	–
Lepton Family number (LF) violating modes					
$e^{\pm}\mu^{\mp}$	*LF*	$< 2 \times 10^{-6}$		CL=90%	504

$h_1(1170)$

$I^G(J^{PC}) = 0^-(1^{+-})$

Mass $m = 1166 \pm 6$ MeV
Full width $\Gamma = 375 \pm 35$ MeV

$b_1(1235)$

$I^G(J^{PC}) = 1^+(1^{+-})$

Mass $m = 1229.5 \pm 3.2$ MeV (S = 1.6)
Full width $\Gamma = 142 \pm 9$ MeV (S = 1.2)

b_1(1235) DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\pi^{\pm}\gamma$	$(1.6 \pm 0.4) \times 10^{-3}$		607
$\pi^+\pi^+\pi^-\pi^0$	< 50 %	84%	535
$(K\overline{K})^{\pm}\pi^0$	< 8 %	90%	248
$K^0_S K^0_L \pi^{\pm}$	< 6 %	90%	235
$K^0_S K^0_S \pi^{\pm}$	< 2 %	90%	235
$\phi\pi$	< 1.5 %	84%	147

See Particle Listings for 3 decay modes that have been seen / not seen.

$a_1(1260)$ [i]

$I^G(J^{PC}) = 1^-(1^{++})$

Mass $m = 1230 \pm 40$ MeV [j]
Full width $\Gamma = 250$ to 600 MeV

$f_2(1270)$

$I^G(J^{PC}) = 0^+(2^{++})$

Mass $m = 1275.5 \pm 0.8$ MeV
Full width $\Gamma = 186.7^{+2.2}_{-2.5}$ MeV (S = 1.4)

$f_2(1270)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\pi\pi$	$(84.2 \,^{+2.9}_{-0.9})$ %	S=1.1	623
$\pi^+\pi^-2\pi^0$	$(7.7 \,^{+1.1}_{-3.2})$ %	S=1.2	563
$K\overline{K}$	$(4.6 \,^{+0.5}_{-0.4})$ %	S=2.7	404
$2\pi^+2\pi^-$	(2.8 ± 0.4) %	S=1.2	560
$\eta\eta$	$(4.0 \pm 0.8) \times 10^{-3}$	S=2.1	326
$4\pi^0$	$(3.0 \pm 1.0) \times 10^{-3}$		565
$\gamma\gamma$	$(1.42 \pm 0.24) \times 10^{-5}$	S=1.4	638
$\eta\pi\pi$	$< 8 \times 10^{-3}$	CL=95%	478
$K^0K^-\pi^+$ + c.c.	$< 3.4 \times 10^{-3}$	CL=95%	293
e^+e^-	$< 6 \times 10^{-10}$	CL=90%	638

$f_1(1285)$

$I^G(J^{PC}) = 0^+(1^{++})$

Mass $m = 1281.9 \pm 0.5$ MeV (S = 1.8)
Full width $\Gamma = 22.7 \pm 1.1$ MeV (S = 1.5)

$f_1(1285)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
4π	(32.7 ± 1.9) %	S=1.2	568
$\pi^0\pi^0\pi^+\pi^-$	(21.8 ± 1.3) %	S=1.2	566
$2\pi^+2\pi^-$	(10.9 ± 0.6) %	S=1.2	563
$\rho^0\pi^+\pi^-$	(10.9 ± 0.6) %	S=1.2	336
$4\pi^0$	$< 7 \times 10^{-4}$	CL=90%	568
$\eta\pi^+\pi^-$	(35 ± 15) %		479
$\eta\pi\pi$	(52.2 ± 2.0) %	S=1.2	482
$a_0(980)\pi$ [ignoring $a_0(980) \to K\overline{K}$]	(38 ± 4) %		238
$\eta\pi\pi$ [excluding $a_0(980)\pi$]	(14 ± 4) %		482
$K\overline{K}\pi$	(9.0 ± 0.4) %	S=1.1	308
$\pi^+\pi^-\pi^0$	$(3.0 \pm 0.9) \times 10^{-3}$		603
$\rho^\pm\pi^\mp$	$< 3.1 \times 10^{-3}$	CL=95%	390
$\gamma\rho^0$	(6.1 ± 1.0) %	S=1.7	406
$\phi\gamma$	$(7.4 \pm 2.6) \times 10^{-4}$		236
e^+e^-	$< 9.4 \times 10^{-9}$	CL=90%	641

See Particle Listings for 2 decay modes that have been seen / not seen.

$\eta(1295)$

$I^G(J^{PC}) = 0^+(0^{-+})$

See the review on "Pseudoscalar and pseudovector mesons in the 1400 MeV region."

Mass $m = 1294 \pm 4$ MeV (S = 1.6)
Full width $\Gamma = 55 \pm 5$ MeV

$\pi(1300)$

$I^G(J^{PC}) = 1^-(0^{-+})$

Mass $m = 1300 \pm 100$ MeV [j]
Full width $\Gamma = 200$ to 600 MeV

$a_2(1320)$

$I^G(J^{PC}) = 1^-(2^{++})$

Mass $m = 1316.9 \pm 0.9$ MeV (S = 1.9)
Full width $\Gamma = 107 \pm 5$ MeV [j]

$a_2(1320)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
3π	(70.1 ± 2.7) %	S=1.2	623
$\eta\pi$	(14.5 ± 1.2) %		535
$\omega\pi\pi$	(10.6 ± 3.2) %	S=1.3	364
$K\overline{K}$	(4.9 ± 0.8) %		436
$\eta'(958)\pi$	$(5.5 \pm 0.9) \times 10^{-3}$		287
$\pi^\pm\gamma$	$(2.91 \pm 0.27) \times 10^{-3}$		651
$\gamma\gamma$	$(9.4 \pm 0.7) \times 10^{-6}$		658
e^+e^-	$< 5 \times 10^{-9}$	CL=90%	658

$f_0(1370)$

$I^G(J^{PC}) = 0^+(0^{++})$

See the review on "Scalar Mesons below 2 GeV."
Mass $m = 1200$ to 1500 MeV
Full width $\Gamma = 200$ to 500 MeV

$\pi_1(1400)$ [k]

$I^G(J^{PC}) = 1^-(1^{-+})$

See the review on "Non-$q\overline{q}$ Mesons."
Mass $m = 1354 \pm 25$ MeV (S = 1.8)
Full width $\Gamma = 330 \pm 35$ MeV

$\eta(1405)$

$I^G(J^{PC}) = 0^+(0^{-+})$

See the review on "Pseudoscalar and Pseudovector Mesons in the 1400 MeV Region."
Mass $m = 1408.8 \pm 2.0$ MeV (S = 2.2)
Full width $\Gamma = 50.1 \pm 2.6$ MeV (S = 1.7)

$\eta(1405)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\rho\rho$	<58 %	99.85%	†

See Particle Listings for 9 decay modes that have been seen / not seen.

$h_1(1415)$

$I^G(J^{PC}) = 0^-(1^{+-})$

was $h_1(1380)$
Mass $m = 1416 \pm 8$ MeV (S = 1.5)
Full width $\Gamma = 90 \pm 15$ MeV

$f_1(1420)$

$I^G(J^{PC}) = 0^+(1^{++})$

See the review on "Pseudoscalar and Pseudovector Mesons in the 1400 MeV Region."

Mass $m = 1426.3 \pm 0.9$ MeV (S = 1.1)

Full width $\Gamma = 54.5 \pm 2.6$ MeV

$\omega(1420)$ [l]

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 1410 \pm 60$ MeV [j]

Full width $\Gamma = 290 \pm 190$ MeV [j]

$a_0(1450)$

$I^G(J^{PC}) = 1^-(0^{++})$

See the review on "Scalar Mesons below 2 GeV."

Mass $m = 1474 \pm 19$ MeV

Full width $\Gamma = 265 \pm 13$ MeV

$a_0(1450)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\pi\eta$	0.093 ± 0.020	627
$\pi\eta'(958)$	0.033 ± 0.017	410
$K\overline{K}$	0.082 ± 0.028	547
$\omega\pi\pi$	**DEFINED AS 1**	484

See Particle Listings for 2 decay modes that have been seen / not seen.

$\rho(1450)$

$I^G(J^{PC}) = 1^+(1^{--})$

See the note in $\rho(1450)$ Particle Listings.

Mass $m = 1465 \pm 25$ MeV [j]

Full width $\Gamma = 400 \pm 60$ MeV [j]

$\eta(1475)$

$I^G(J^{PC}) = 0^+(0^{-+})$

See the review on "Pseudoscalar and Pseudovector Mesons in the 1400 MeV Region."

Mass $m = 1475 \pm 4$ MeV (S = 1.4)

Full width $\Gamma = 90 \pm 9$ MeV (S = 1.6)

$f_0(1500)$

$I^G(J^{PC}) = 0^+(0^{++})$

See the reviews on "Scalar Mesons below 2 GeV" and on "Non-$q\overline{q}$ Mesons".

Mass $m = 1506 \pm 6$ MeV (S = 1.4)

Full width $\Gamma = 112 \pm 9$ MeV

$f_0(1500)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor	p (MeV/c)
$\pi\pi$	(34.5 ± 2.2) %	1.2	741
4π	(48.9 ± 3.3) %	1.2	692

$\eta\eta$	(6.0±0.9) %	1.1	517
$\eta\eta'(958)$	(2.2±0.8) %	1.4	20
$K\overline{K}$	(8.5±1.0) %	1.1	569

See Particle Listings for 9 decay modes that have been seen / not seen.

$f_2'(1525)$

$I^G(J^{PC}) = 0^+(2^{++})$

Mass $m = 1517.4 \pm 2.5$ MeV (S = 2.8)
Full width $\Gamma = 86 \pm 5$ MeV (S = 2.2)

$f_2'(1525)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor	p (MeV/c)
$K\overline{K}$	(87.6±2.2) %	1.1	576
$\eta\eta$	(11.6±2.2) %	1.1	525
$\pi\pi$	(8.3±1.6) $\times 10^{-3}$		747
$\gamma\gamma$	(9.5±1.1) $\times 10^{-7}$	1.1	759

$\pi_1(1600)$

$I^G(J^{PC}) = 1^-(1^{-+})$

See the review on "Non-$q\overline{q}$ Mesons" and a note in PDG 06, Journal of Physics **G33** 1 (2006).

Mass $m = 1660^{+15}_{-11}$ MeV (S = 1.2)
Full width $\Gamma = 257 \pm 60$ MeV (S = 1.9)

$a_1(1640)$

$I^G(J^{PC}) = 1^-(1^{++})$

Mass $m = 1655 \pm 16$ MeV (S = 1.2)
Full width $\Gamma = 254 \pm 40$ MeV (S = 1.8)

$\eta_2(1645)$

$I^G(J^{PC}) = 0^+(2^{-+})$

Mass $m = 1617 \pm 5$ MeV
Full width $\Gamma = 181 \pm 11$ MeV

$\omega(1650)$ [n]

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 1670 \pm 30$ MeV [j]
Full width $\Gamma = 315 \pm 35$ MeV [j]

$\omega_3(1670)$

$I^G(J^{PC}) = 0^-(3^{--})$

Mass $m = 1667 \pm 4$ MeV
Full width $\Gamma = 168 \pm 10$ MeV

$\pi_2(1670)$

$I^G(J^{PC}) = 1^-(2^{-+})$

Mass $m = 1670.6^{+2.9}_{-1.2}$ MeV (S = 1.3)
Full width $\Gamma = 258^{+8}_{-9}$ MeV (S = 1.2)

$\pi_2(1670)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
3π	(95.8 ± 1.4) %		808
$f_2(1270)\pi$	(56.3 ± 3.2) %		327
$\rho\pi$	$(31\ \pm4\ )$ %		647
$\sigma\pi$	$(10\ \pm4\ )$ %		–
$\pi(\pi\pi)_{S\text{-wave}}$	$(\ 8.7\pm3.4)$ %		–
$\pi^\pm\pi^+\pi^-$	$(53\ \pm4\ )$ %		806
$K\overline{K}^*(892)+$ c.c.	$(\ 4.2\pm1.4)$ %		453
$\omega\rho$	$(\ 2.7\pm1.1)$ %		302
$\pi^\pm\gamma$	$(\ 7.0\pm1.2)\times10^{-4}$		829
$\gamma\gamma$	$<\ 2.8\ \times10^{-7}$	90%	835
$\eta\pi$	$<\ 5$ %		739
$\pi^\pm2\pi^+2\pi^-$	$<\ 5$ %		735
$\rho(1450)\pi$	$<\ 3.6\ \times10^{-3}$	97.7%	145
$b_1(1235)\pi$	$<\ 1.9\ \times10^{-3}$	97.7%	364

See Particle Listings for 2 decay modes that have been seen / not seen.

$\phi(1680)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 1680 \pm 20$ MeV [j]
Full width $\Gamma = 150 \pm 50$ MeV [j]

$\rho_3(1690)$

$I^G(J^{PC}) = 1^+(3^{--})$

Mass $m = 1688.8 \pm 2.1$ MeV
Full width $\Gamma = 161 \pm 10$ MeV (S = 1.5)

$\rho_3(1690)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor	p (MeV/c)
4π	$(71.1\ \pm\ 1.9\ )$ %		790
$\pi^\pm\pi^+\pi^-\pi^0$	$(67\ \pm22\ )$ %		787
$\omega\pi$	$(16\ \pm\ 6\ )$ %		655
$\pi\pi$	$(23.6\ \pm\ 1.3\ )$ %		834
$K\overline{K}\pi$	$(\ 3.8\ \pm\ 1.2\ )$ %		629
$K\overline{K}$	$(\ 1.58\pm\ 0.26)$ %	1.2	685

See Particle Listings for 5 decay modes that have been seen / not seen.

$\rho(1700)$

$I^G(J^{PC}) = 1^+(1^{--})$

See the note in $\rho(1700)$ Particle Listings.

Mass $m = 1720 \pm 20$ MeV [j] ($\eta\rho^0$ and $\pi^+\pi^-$ modes)
Full width $\Gamma = 250 \pm 100$ MeV [j] ($\eta\rho^0$ and $\pi^+\pi^-$ modes)

$a_2(1700)$

$I^G(J^{PC}) = 1^-(2^{++})$

Mass $m = 1705 \pm 40$ MeV
Full width $\Gamma = 258 \pm 40$ MeV

$a_2(1700)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\eta\pi$	$(3.7\ \pm1.0\ )$ %	758
$\gamma\gamma$	$(1.16\pm0.27)\times10^{-6}$	852
$K\overline{K}$	$(1.9\ \pm1.2\ )$ %	695

See Particle Listings for 4 decay modes that have been seen / not seen.

$f_0(1710)$

$I^G(J^{PC}) = 0^+(0^{++})$

See the review on "Non-$q\overline{q}$ Mesons."

Mass $m = 1704 \pm 12$ MeV

Full width $\Gamma = 123 \pm 18$ MeV

$\pi(1800)$

$I^G(J^{PC}) = 1^-(0^{-+})$

Mass $m = 1810^{+\ 9}_{-11}$ MeV (S = 2.2)

Full width $\Gamma = 215^{+7}_{-8}$ MeV

$\phi_3(1850)$

$I^G(J^{PC}) = 0^-(3^{--})$

Mass $m = 1854 \pm 7$ MeV

Full width $\Gamma = 87^{+28}_{-23}$ MeV (S = 1.2)

$\eta_2(1870)$

$I^G(J^{PC}) = 0^+(2^{-+})$

Mass $m = 1842 \pm 8$ MeV

Full width $\Gamma = 225 \pm 14$ MeV

$\pi_2(1880)$

$I^G(J^{PC}) = 1^-(2^{-+})$

Mass $m = 1874^{+26}_{-\ 5}$ MeV (S = 1.6)

Full width $\Gamma = 237^{+33}_{-30}$ MeV (S = 1.2)

$f_2(1950)$

$I^G(J^{PC}) = 0^+(2^{++})$

Mass $m = 1936 \pm 12$ MeV (S = 1.3)

Full width $\Gamma = 464 \pm 24$ MeV

$a_4(1970)$

$I^G(J^{PC}) = 1^-(4^{++})$

was $a_4(2040)$

Mass $m = 1967 \pm 16$ MeV (S = 2.1)

Full width $\Gamma = 324^{+15}_{-18}$ MeV

$f_2(2010)$

$I^G(J^{PC}) = 0^+(2^{++})$

Mass $m = 2011^{+60}_{-80}$ MeV

Full width $\Gamma = 202 \pm 60$ MeV

$f_4(2050)$

$I^G(J^{PC}) = 0^+(4^{++})$

Mass $m = 2018 \pm 11$ MeV (S = 2.1)
Full width $\Gamma = 237 \pm 18$ MeV (S = 1.9)

$f_4(2050)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\pi\pi$	(17.0 ± 1.5) %	1000
$K\overline{K}$	$(6.8^{+3.4}_{-1.8}) \times 10^{-3}$	880
$\eta\eta$	$(2.1\pm0.8) \times 10^{-3}$	848
$4\pi^0$	$<$ 1.2 %	964

See Particle Listings for 2 decay modes that have been seen / not seen.

$\phi(2170)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 2160 \pm 80$ MeV [j]
Full width $\Gamma = 125 \pm 65$ MeV [j]

$f_2(2300)$

$I^G(J^{PC}) = 0^+(2^{++})$

Mass $m = 2297 \pm 28$ MeV
Full width $\Gamma = 149 \pm 40$ MeV

$f_2(2340)$

$I^G(J^{PC}) = 0^+(2^{++})$

Mass $m = 2345^{+50}_{-40}$ MeV
Full width $\Gamma = 322^{+70}_{-60}$ MeV

STRANGE MESONS
$(S = \pm1, C = B = 0)$

$K^+ = u\overline{s}$, $K^0 = d\overline{s}$, $\overline{K}^0 = \overline{d}s$, $K^- = \overline{u}s$, similarly for K^*'s

$K^\pm$

$I(J^P) = \frac{1}{2}(0^-)$

Mass $m = 493.677 \pm 0.016$ MeV [o] (S = 2.8)
Mean life $\tau = (1.2380 \pm 0.0020) \times 10^{-8}$ s (S = 1.8)
$c\tau = 3.711$ m

CPT violation parameters (Δ = rate difference/sum)

$\Delta(K^\pm \to \mu^\pm\nu_\mu) = (-0.27 \pm 0.21)\%$
$\Delta(K^\pm \to \pi^\pm\pi^0) = (0.4 \pm 0.6)\%$ [p]

CP violation parameters (Δ = rate difference/sum)

$\Delta(K^\pm \to \pi^\pm e^+e^-) = (-2.2 \pm 1.6) \times 10^{-2}$
$\Delta(K^\pm \to \pi^\pm\mu^+\mu^-) = 0.010 \pm 0.023$
$\Delta(K^\pm \to \pi^\pm\pi^0\gamma) = (0.0 \pm 1.2) \times 10^{-3}$
$\Delta(K^\pm \to \pi^\pm\pi^+\pi^-) = (0.04 \pm 0.06)\%$
$\Delta(K^\pm \to \pi^\pm\pi^0\pi^0) = (-0.02 \pm 0.28)\%$

T violation parameters

$K^+ \to \pi^0 \mu^+ \nu_\mu$ $P_T = (-1.7 \pm 2.5) \times 10^{-3}$

$K^+ \to \mu^+ \nu_\mu \gamma$ $P_T = (-0.6 \pm 1.9) \times 10^{-2}$

$K^+ \to \pi^0 \mu^+ \nu_\mu$ $\text{Im}(\xi) = -0.006 \pm 0.008$

Slope parameter g [q]

(See Particle Listings for quadratic coefficients and alternative parametrization related to $\pi\pi$ scattering)

$K^\pm \to \pi^\pm \pi^+ \pi^-$ $g = -0.21134 \pm 0.00017$

$(g_+ - g_-) / (g_+ + g_-) = (-1.5 \pm 2.2) \times 10^{-4}$

$K^\pm \to \pi^\pm \pi^0 \pi^0$ $g = 0.626 \pm 0.007$

$(g_+ - g_-) / (g_+ + g_-) = (1.8 \pm 1.8) \times 10^{-4}$

$K^\pm$ decay form factors [a,r]

Assuming μ-e universality

$\lambda_+(K^+_{\mu 3}) = \lambda_+(K^+_{e3}) = (2.959 \pm 0.025) \times 10^{-2}$

$\lambda_0(K^+_{\mu 3}) = (1.76 \pm 0.25) \times 10^{-2}$ (S = 2.7)

Not assuming μ-e universality

$\lambda_+(K^+_{e3}) = (2.956 \pm 0.025) \times 10^{-2}$

$\lambda_+(K^+_{\mu 3}) = (3.09 \pm 0.25) \times 10^{-2}$ (S = 1.5)

$\lambda_0(K^+_{\mu 3}) = (1.73 \pm 0.27) \times 10^{-2}$ (S = 2.6)

K_{e3} form factor quadratic fit

λ'_+ $(K^\pm_{e3})$ linear coeff. $= (2.59 \pm 0.04) \times 10^{-2}$

$\lambda''_+(K^\pm_{e3})$ quadratic coeff. $= (0.186 \pm 0.021) \times 10^{-2}$

λ'_+ (LINEAR $K^\pm_{\mu 3}$ FORM FACTOR FROM QUADRATIC FIT) $= (24 \pm 4) \times 10^{-3}$

λ''_+ (QUADRATIC $K^\pm_{\mu 3}$ FORM FACTOR) $= (1.8 \pm 1.5) \times 10^{-3}$

M_V (VECTOR POLE MASS FOR $K^\pm_{e3}$ DECAY) $= 890.3 \pm 2.8$ MeV

M_V (VECTOR POLE MASS FOR $K^\pm_{\mu 3}$ DECAY) $= 878 \pm 12$ MeV

M_S (SCALAR POLE MASS FOR $K^\pm_{\mu 3}$ DECAY) $= 1215 \pm 50$ MeV

Λ_+ (DISPERSIVE VECTOR FORM FACTOR IN $K^\pm_{e3}$ DECAY) $= (2.460 \pm 0.017) \times 10^{-2}$

Λ_+ (DISPERSIVE VECTOR FORM FACTOR IN $K^\pm_{\mu 3}$ DECAY) $= (25.4 \pm 0.9) \times 10^{-3}$

$\ln(C)$ (DISPERSIVE SCALAR FORM FACTOR in $K^\pm_{\mu 3}$ decays) $= (182 \pm 16) \times 10^{-3}$

K^+_{e3} $|f_S/f_+| = (-0.08^{+0.34}_{-0.40}) \times 10^{-2}$

K^+_{e3} $|f_T/f_+| = (-1.2^{+1.3}_{-1.1}) \times 10^{-2}$

$K^+_{\mu 3}$ $|f_S/f_+| = (0.2 \pm 0.6) \times 10^{-2}$

$K^+_{\mu 3}$ $|f_T/f_+| = (-0.1 \pm 0.7) \times 10^{-2}$

$K^+ \to e^+ \nu_e \gamma$ $|F_A + F_V| = 0.133 \pm 0.008$ (S = 1.3)

$K^+ \to \mu^+ \nu_\mu \gamma$ $|F_A + F_V| = 0.165 \pm 0.013$

$K^+ \to e^+ \nu_e \gamma$ $|F_A - F_V| < 0.49$, CL = 90%

$K^+ \to \mu^+ \nu_\mu \gamma$ $|F_A - F_V| = -0.153 \pm 0.033$ (S = 1.1)

Charge radius

$\langle r \rangle = 0.560 \pm 0.031$ fm

Forward-backward asymmetry

$A_{FB}(K^{\pm}_{\pi\mu\mu}) = \frac{\Gamma(cos(\theta_{K\mu})>0)-\Gamma(cos(\theta_{K\mu})<0)}{\Gamma(cos(\theta_{K\mu})>0)+\Gamma(cos(\theta_{K\mu})<0)} < 2.3 \times 10^{-2}$, CL = 90%

K^- modes are charge conjugates of the modes below.

K^+ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Leptonic and semileptonic modes				
$e^+\nu_e$		(1.582±0.007) × 10^{-5}		247
$\mu^+\nu_\mu$		(63.56 ±0.11) %	S=1.2	236
$\pi^0 e^+\nu_e$		(5.07 ±0.04) %	S=2.1	228
Called K^+_{e3}.				
$\pi^0\mu^+\nu_\mu$		(3.352±0.033) %	S=1.9	215
Called $K^+_{\mu3}$.				
$\pi^0\pi^0 e^+\nu_e$		(2.55 ±0.04) × 10^{-5}	S=1.1	206
$\pi^+\pi^- e^+\nu_e$		(4.247±0.024) × 10^{-5}		203
$\pi^+\pi^-\mu^+\nu_\mu$		(1.4 ±0.9) × 10^{-5}		151
$\pi^0\pi^0\pi^0 e^+\nu_e$		< 3.5 × 10^{-6}	CL=90%	135
Hadronic modes				
$\pi^+\pi^0$		(20.67 ±0.08) %	S=1.2	205
$\pi^+\pi^0\pi^0$		(1.760±0.023) %	S=1.1	133
$\pi^+\pi^+\pi^-$		(5.583±0.024) %		125
Leptonic and semileptonic modes with photons				
$\mu^+\nu_\mu\gamma$	[s,t]	(6.2 ±0.8) × 10^{-3}		236
$\mu^+\nu_\mu\gamma(SD^+)$	[a,u]	(1.33 ±0.22) × 10^{-5}		–
$\mu^+\nu_\mu\gamma(SD^+INT)$	[a,u]	< 2.7 × 10^{-5}	CL=90%	–
$\mu^+\nu_\mu\gamma(SD^- + SD^-INT)$	[a,u]	< 2.6 × 10^{-4}	CL=90%	–
$e^+\nu_e\gamma$		(9.4 ±0.4) × 10^{-6}		247
$\pi^0 e^+\nu_e\gamma$	[s,t]	(2.56 ±0.16) × 10^{-4}		228
$\pi^0 e^+\nu_e\gamma(SD)$	[a,u]	< 5.3 × 10^{-5}	CL=90%	228
$\pi^0\mu^+\nu_\mu\gamma$	[s,t]	(1.25 ±0.25) × 10^{-5}		215
$\pi^0\pi^0 e^+\nu_e\gamma$		< 5 × 10^{-6}	CL=90%	206
Hadronic modes with photons or $\ell\overline{\ell}$ pairs				
$\pi^+\pi^0\gamma(INT)$		(− 4.2 ±0.9) × 10^{-6}		–
$\pi^+\pi^0\gamma(DE)$	[s,v]	(6.0 ±0.4) × 10^{-6}		205
$\pi^+\pi^0 e^+e^-$		(4.24 ±0.14) × 10^{-6}		205
$\pi^+\pi^0\pi^0\gamma$	[s,t]	(7.6 $^{+6.0}_{-3.0}$) × 10^{-6}		133
$\pi^+\pi^+\pi^-\gamma$	[s,t]	(7.1 ±0.5) × 10^{-6}		125
$\pi^+\gamma\gamma$	[s]	(1.01 ±0.06) × 10^{-6}		227
$\pi^+3\gamma$	[s]	< 1.0 × 10^{-4}	CL=90%	227
$\pi^+e^+e^-\gamma$		(1.19 ±0.13) × 10^{-8}		227
Leptonic modes with $\ell\overline{\ell}$ pairs				
$e^+\nu_e\nu\overline{\nu}$		< 6 × 10^{-5}	CL=90%	247
$\mu^+\nu_\mu\nu\overline{\nu}$		< 2.4 × 10^{-6}	CL=90%	236
$e^+\nu_e e^+e^-$		(2.48 ±0.20) × 10^{-8}		247
$\mu^+\nu_\mu e^+e^-$		(7.06 ±0.31) × 10^{-8}		236
$e^+\nu_e\mu^+\mu^-$		(1.7 ±0.5) × 10^{-8}		223
$\mu^+\nu_\mu\mu^+\mu^-$		< 4.1 × 10^{-7}	CL=90%	185

Lepton family number (*LF*), Lepton number (*L*), $\Delta S = \Delta Q$ (*SQ*) violating modes, or $\Delta S = 1$ weak neutral current (*S1*) modes

$\pi^+ \pi^+ e^- \overline{\nu}_e$	*SQ*		< 1.3	$\times 10^{-8}$	CL=90%	203
$\pi^+ \pi^+ \mu^- \overline{\nu}_\mu$	*SQ*		< 3.0	$\times 10^{-6}$	CL=95%	151
$\pi^+ e^+ e^-$	*S1*		(3.00 ± 0.09)	$\times 10^{-7}$		227
$\pi^+ \mu^+ \mu^-$	*S1*		(9.4 ± 0.6)	$\times 10^{-8}$	S=2.6	172
$\pi^+ \nu \overline{\nu}$	*S1*		(1.7 ± 1.1)	$\times 10^{-10}$		227
$\pi^+ \pi^0 \nu \overline{\nu}$	*S1*		< 4.3	$\times 10^{-5}$	CL=90%	205
$\mu^- \nu e^+ e^+$	*LF*		< 2.1	$\times 10^{-8}$	CL=90%	236
$\mu^+ \nu_e$	*LF*	[d]	< 4	$\times 10^{-3}$	CL=90%	236
$\pi^+ \mu^+ e^-$	*LF*		< 1.3	$\times 10^{-11}$	CL=90%	214
$\pi^+ \mu^- e^+$	*LF*		< 5.2	$\times 10^{-10}$	CL=90%	214
$\pi^- \mu^+ e^+$	*L*		< 5.0	$\times 10^{-10}$	CL=90%	214
$\pi^- e^+ e^+$	*L*		< 2.2	$\times 10^{-10}$	CL=90%	227
$\pi^- \mu^+ \mu^+$	*L*		< 4.2	$\times 10^{-11}$	CL=90%	172
$\mu^+ \overline{\nu}_e$	*L*	[d]	< 3.3	$\times 10^{-3}$	CL=90%	236
$\pi^0 e^+ \overline{\nu}_e$	*L*		< 3	$\times 10^{-3}$	CL=90%	228
$\pi^+ \gamma$		[x]	< 2.3	$\times 10^{-9}$	CL=90%	227

K^0

$I(J^P) = \frac{1}{2}(0^-)$

50% K_S, 50% K_L

Mass $m = 497.611 \pm 0.013$ MeV (S = 1.2)

$m_{K^0} - m_{K^\pm} = 3.934 \pm 0.020$ MeV (S = 1.6)

Mean square charge radius

$\langle r^2 \rangle = -0.077 \pm 0.010$ fm^2

***T*-violation parameters in K^0-$\overline{K}^0$ mixing** [r]

Asymmetry A_T in K^0-$\overline{K}^0$ mixing $= (6.6 \pm 1.6) \times 10^{-3}$

***CP*-violation parameters**

Re(ϵ) $= (1.596 \pm 0.013) \times 10^{-3}$

***CPT*-violation parameters** [r]

Re $\delta = (2.5 \pm 2.3) \times 10^{-4}$

Im $\delta = (-1.5 \pm 1.6) \times 10^{-5}$

Re(y), K_{e3} parameter $= (0.4 \pm 2.5) \times 10^{-3}$

Re(x_-), K_{e3} parameter $= (-2.9 \pm 2.0) \times 10^{-3}$

$|m_{K^0} - m_{\overline{K}^0}| \,/\, m_{\text{average}} < 6 \times 10^{-19}$, CL = 90% [y]

$(\Gamma_{K^0} - \Gamma_{\overline{K}^0})/m_{\text{average}} = (8 \pm 8) \times 10^{-18}$

Tests of $\Delta S = \Delta Q$

Re(x_+), K_{e3} parameter $= (-0.9 \pm 3.0) \times 10^{-3}$

K^0_S

$I(J^P) = \frac{1}{2}(0^-)$

Mean life $\tau = (0.8954 \pm 0.0004) \times 10^{-10}$ s (S = 1.1) Assuming *CPT*

Mean life $\tau = (0.89564 \pm 0.00033) \times 10^{-10}$ s Not assuming *CPT*

$c\tau = 2.6844$ cm Assuming *CPT*

CP-violation parameters [z]

$\mathrm{Im}(\eta_{+-0}) = -0.002 \pm 0.009$
$\mathrm{Im}(\eta_{000}) = -0.001 \pm 0.016$
$|\eta_{000}| = |A(K^0_S \to 3\pi^0)/A(K^0_L \to 3\pi^0)| < 0.0088$, CL = 90%
CP asymmetry *A* in $\pi^+\pi^- e^+ e^- = (-0.4 \pm 0.8)\%$

K^0_S DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	*p* (MeV/*c*)
Hadronic modes				
$\pi^0\pi^0$		(30.69 ± 0.05) %		209
$\pi^+\pi^-$		(69.20 ± 0.05) %		206
$\pi^+\pi^-\pi^0$		$(3.5\ ^{+1.1}_{-0.9}) \times 10^{-7}$		133
Modes with photons or $\ell\overline{\ell}$ pairs				
$\pi^+\pi^-\gamma$	[t,aa]	$(1.79\pm0.05) \times 10^{-3}$		206
$\pi^+\pi^- e^+ e^-$		$(4.79\pm0.15) \times 10^{-5}$		206
$\pi^0\gamma\gamma$	[aa]	$(4.9\ \pm1.8\ ) \times 10^{-8}$		230
$\gamma\gamma$		$(2.63\pm0.17) \times 10^{-6}$	S=3.0	249
Semileptonic modes				
$\pi^\pm e^\mp \nu_e$	[bb]	$(7.04\pm0.08) \times 10^{-4}$		229
***CP* violating (*CP*) and $\Delta S = 1$ weak neutral current (*S1*) modes**				
$3\pi^0$	*CP*	$< 2.6 \times 10^{-8}$	CL=90%	139
$\mu^+\mu^-$	*S1*	$< 8 \times 10^{-10}$	CL=90%	225
e^+e^-	*S1*	$< 9 \times 10^{-9}$	CL=90%	249
$\pi^0 e^+ e^-$	*S1* [aa]	$(3.0\ ^{+1.5}_{-1.2}) \times 10^{-9}$		230
$\pi^0\mu^+\mu^-$	*S1*	$(2.9\ ^{+1.5}_{-1.2}) \times 10^{-9}$		177

K^0_L

$I(J^P) = \frac{1}{2}(0^-)$

$m_{K_L} - m_{K_S}$
$= (0.5293 \pm 0.0009) \times 10^{10}\ \hbar\ \mathrm{s}^{-1}$ (S = 1.3) Assuming *CPT*
$= (3.484 \pm 0.006) \times 10^{-12}$ MeV Assuming *CPT*
$= (0.5289 \pm 0.0010) \times 10^{10}\ \hbar\ \mathrm{s}^{-1}$ Not assuming *CPT*

Mean life $\tau = (5.116 \pm 0.021) \times 10^{-8}$ s (S = 1.1)
$c\tau = 15.34$ m

Slope parameters [q]

(See Particle Listings for other linear and quadratic coefficients)

$K^0_L \to \pi^+\pi^-\pi^0$: $g = 0.678 \pm 0.008$ (S = 1.5)
$K^0_L \to \pi^+\pi^-\pi^0$: $h = 0.076 \pm 0.006$
$K^0_L \to \pi^+\pi^-\pi^0$: $k = 0.0099 \pm 0.0015$
$K^0_L \to \pi^0\pi^0\pi^0$: $h = (0.6 \pm 1.2) \times 10^{-3}$

K_L decay form factors [r]

Linear parametrization assuming μ-e universality

$\lambda_+(K^0_{\mu3}) = \lambda_+(K^0_{e3}) = (2.82 \pm 0.04) \times 10^{-2}$ (S = 1.1)
$\lambda_0(K^0_{\mu3}) = (1.38 \pm 0.18) \times 10^{-2}$ (S = 2.2)

Quadratic parametrization assuming μ-e universality

$\lambda'_+(K^0_{\mu 3}) = \lambda'_+(K^0_{e3}) = (2.40 \pm 0.12) \times 10^{-2}$ (S = 1.2)

$\lambda''_+(K^0_{\mu 3}) = \lambda''_+(K^0_{e3}) = (0.20 \pm 0.05) \times 10^{-2}$ (S = 1.2)

$\lambda_0(K^0_{\mu 3}) = (1.16 \pm 0.09) \times 10^{-2}$ (S = 1.2)

Pole parametrization assuming μ-e universality

$M^{\mu}_{V}(K^0_{\mu 3}) = M^{e}_{V}(K^0_{e3}) = 878 \pm 6$ MeV (S = 1.1)

$M^{\mu}_{S}(K^0_{\mu 3}) = 1252 \pm 90$ MeV (S = 2.6)

Dispersive parametrization assuming μ-e universality

$\Lambda_+ = (2.51 \pm 0.06) \times 10^{-2}$ (S = 1.5)

$\ln(C) = (1.75 \pm 0.18) \times 10^{-1}$ (S = 2.0)

K^0_{e3} $|f_S/f_+| = (1.5^{+1.4}_{-1.6}) \times 10^{-2}$

K^0_{e3} $|f_T/f_+| = (5^{+4}_{-5}) \times 10^{-2}$

$K^0_{\mu 3}$ $|f_T/f_+| = (12 \pm 12) \times 10^{-2}$

$K_L \to \ell^+ \ell^- \gamma$, $K_L \to \ell^+ \ell^- \ell'^+ \ell'^-$: $\alpha_{K^*} = -0.205 \pm 0.022$ (S = 1.8)

$K^0_L \to \ell^+ \ell^- \gamma$, $K^0_L \to \ell^+ \ell^- \ell'^+ \ell'^-$: $\alpha_{DIP} = -1.69 \pm 0.08$ (S = 1.7)

$K_L \to \pi^+ \pi^- e^+ e^-$: $a_1/a_2 = -0.737 \pm 0.014$ GeV^2

$K_L \to \pi^0 2\gamma$: $a_V = -0.43 \pm 0.06$ (S = 1.5)

CP-violation parameters [z]

$A_L = (0.332 \pm 0.006)\%$

$|\eta_{00}| = (2.220 \pm 0.011) \times 10^{-3}$ (S = 1.8)

$|\eta_{+-}| = (2.232 \pm 0.011) \times 10^{-3}$ (S = 1.8)

$|\epsilon| = (2.228 \pm 0.011) \times 10^{-3}$ (S = 1.8)

$|\eta_{00}/\eta_{+-}| = 0.9950 \pm 0.0007$ [cc] (S = 1.6)

$\text{Re}(\epsilon'/\epsilon) = (1.66 \pm 0.23) \times 10^{-3}$ [cc] (S = 1.6)

Assuming *CPT*

$\phi_{+-} = (43.51 \pm 0.05)^\circ$ (S = 1.2)

$\phi_{00} = (43.52 \pm 0.05)^\circ$ (S = 1.3)

$\phi_{\epsilon} = \phi_{SW} = (43.52 \pm 0.05)^\circ$ (S = 1.2)

$\text{Im}(\epsilon'/\epsilon) = -(\phi_{00} - \phi_{+-})/3 = (-0.002 \pm 0.005)^\circ$ (S = 1.7)

Not assuming *CPT*

$\phi_{+-} = (43.4 \pm 0.5)^\circ$ (S = 1.2)

$\phi_{00} = (43.7 \pm 0.6)^\circ$ (S = 1.2)

$\phi_{\epsilon} = (43.5 \pm 0.5)^\circ$ (S = 1.3)

CP asymmetry *A* in $K^0_L \to \pi^+ \pi^- e^+ e^- = (13.7 \pm 1.5)\%$

β_{CP} from $K^0_L \to e^+ e^- e^+ e^- = -0.19 \pm 0.07$

γ_{CP} from $K^0_L \to e^+ e^- e^+ e^- = 0.01 \pm 0.11$ (S = 1.6)

j for $K^0_L \to \pi^+ \pi^- \pi^0 = 0.0012 \pm 0.0008$

f for $K^0_L \to \pi^+ \pi^- \pi^0 = 0.004 \pm 0.006$

$|\eta_{+-\gamma}| = (2.35 \pm 0.07) \times 10^{-3}$

$\phi_{+-\gamma} = (44 \pm 4)^\circ$

$\left|\epsilon'_{+-\gamma}\right|/\epsilon$ < 0.3, CL = 90%
$\left|g_{E1}\right|$ for $K^0_L \to \pi^+\pi^-\gamma$ < 0.21, CL = 90%

T-violation parameters

Im(ξ) in $K^0_{\mu 3}$ = −0.007 ± 0.026

CPT invariance tests

$\phi_{00} - \phi_{+-}$ = (0.34 ± 0.32)°
Re($\frac{2}{3}\eta_{+-} + \frac{1}{3}\eta_{00}$)$-\frac{A_L}{2}$ = (−3 ± 35) × 10^{-6}

$\Delta S = -\Delta Q$ in $K^0_{\ell 3}$ decay

Re x = −0.002 ± 0.006
Im x = 0.0012 ± 0.0021

K^0_L DECAY MODES			Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Semileptonic modes					
$\pi^\pm e^\mp \nu_e$		[bb]	(40.55 ±0.11) %	S=1.7	229
Called K^0_{e3}.					
$\pi^\pm \mu^\mp \nu_\mu$		[bb]	(27.04 ±0.07) %	S=1.1	216
Called $K^0_{\mu 3}$.					
($\pi\mu$atom)ν			(1.05 ±0.11) × 10^{-7}		188
$\pi^0\pi^\pm e^\mp \nu$		[bb]	(5.20 ±0.11) × 10^{-5}		207
$\pi^\pm e^\mp \nu e^+ e^-$		[bb]	(1.26 ±0.04) × 10^{-5}		229
Hadronic modes, including Charge conjugation×Parity Violating (CPV) modes					
$3\pi^0$			(19.52 ±0.12) %	S=1.6	139
$\pi^+\pi^-\pi^0$			(12.54 ±0.05) %		133
$\pi^+\pi^-$	CPV	[dd]	(1.967±0.010) × 10^{-3}	S=1.5	206
$\pi^0\pi^0$	CPV		(8.64 ±0.06) × 10^{-4}	S=1.8	209
Semileptonic modes with photons					
$\pi^\pm e^\mp \nu_e \gamma$		[t,bb,ee]	(3.79 ±0.06) × 10^{-3}		229
$\pi^\pm \mu^\mp \nu_\mu \gamma$			(5.65 ±0.23) × 10^{-4}		216
Hadronic modes with photons or $\ell\bar{\ell}$ pairs					
$\pi^0\pi^0\gamma$			< 2.43 × 10^{-7}	CL=90%	209
$\pi^+\pi^-\gamma$		[t,ee]	(4.15 ±0.15) × 10^{-5}	S=2.8	206
$\pi^+\pi^-\gamma$(DE)			(2.84 ±0.11) × 10^{-5}	S=2.0	206
$\pi^0 2\gamma$		[ee]	(1.273±0.033) × 10^{-6}		230
$\pi^0\gamma e^+ e^-$			(1.62 ±0.17) × 10^{-8}		230
Other modes with photons or $\ell\bar{\ell}$ pairs					
2γ			(5.47 ±0.04) × 10^{-4}	S=1.1	249
3γ			< 7.4 × 10^{-8}	CL=90%	249
$e^+e^-\gamma$			(9.4 ±0.4) × 10^{-6}	S=2.0	249
$\mu^+\mu^-\gamma$			(3.59 ±0.11) × 10^{-7}	S=1.3	225
$e^+e^-\gamma\gamma$		[ee]	(5.95 ±0.33) × 10^{-7}		249
$\mu^+\mu^-\gamma\gamma$		[ee]	(1.0 $^{+0.8}_{-0.6}$) × 10^{-8}		225
Charge conjugation × Parity (CP) or Lepton Family number (LF) violating modes, or $\Delta S = 1$ weak neutral current ($S1$) modes					
$\mu^+\mu^-$	S1		(6.84 ±0.11) × 10^{-9}		225
e^+e^-	S1		(9 $^{+6}_{-4}$) × 10^{-12}		249
$\pi^+\pi^-e^+e^-$	S1	[ee]	(3.11 ±0.19) × 10^{-7}		206

$\pi^0 \pi^0 e^+ e^-$	*S1*	<	6.6	$\times 10^{-9}$	CL=90%	209
$\pi^0 \pi^0 \mu^+ \mu^-$	*S1*	<	9.2	$\times 10^{-11}$	CL=90%	57
$\mu^+ \mu^- e^+ e^-$	*S1*		(2.69 ±0.27)	$\times 10^{-9}$		225
$e^+ e^- e^+ e^-$	*S1*		(3.56 ±0.21)	$\times 10^{-8}$		249
$\pi^0 \mu^+ \mu^-$	*CP,S1* [ff]	<	3.8	$\times 10^{-10}$	CL=90%	177
$\pi^0 e^+ e^-$	*CP,S1* [ff]	<	2.8	$\times 10^{-10}$	CL=90%	230
$\pi^0 \nu \overline{\nu}$	*CP,S1* [gg]	<	3.0	$\times 10^{-9}$	CL=90%	230
$\pi^0 \pi^0 \nu \overline{\nu}$	*S1*	<	8.1	$\times 10^{-7}$	CL=90%	209
$e^\pm \mu^\mp$	*LF* [bb]	<	4.7	$\times 10^{-12}$	CL=90%	238
$e^\pm e^\pm \mu^\mp \mu^\mp$	*LF* [bb]	<	4.12	$\times 10^{-11}$	CL=90%	225
$\pi^0 \mu^\pm e^\mp$	*LF* [bb]	<	7.6	$\times 10^{-11}$	CL=90%	217
$\pi^0 \pi^0 \mu^\pm e^\mp$	*LF*	<	1.7	$\times 10^{-10}$	CL=90%	159

$K_0^*(700)$

$I(J^P) = \frac{1}{2}(0^+)$

also known as κ; was $K_0^*(800)$

Mass (T-Matrix Pole $\sqrt{s}$) = (630–730) − i (260–340) MeV
Mass (Breit-Wigner) = 824 ± 30 MeV
Full width (Breit-Wigner) = 478 ± 50 MeV

$K_0^*(700)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\pi$	100 %	240

$K^*(892)$

$I(J^P) = \frac{1}{2}(1^-)$

$K^*(892)^\pm$ hadroproduced mass m = 891.66 ± 0.26 MeV
$K^*(892)^\pm$ in τ decays mass m = 895.5 ± 0.8 MeV
$K^*(892)^0$ mass m = 895.55 ± 0.20 MeV (S = 1.7)
$K^*(892)^\pm$ hadroproduced full width Γ = 50.8 ± 0.9 MeV
$K^*(892)^\pm$ in τ decays full width Γ = 46.2 ± 1.3 MeV
$K^*(892)^0$ full width Γ = 47.3 ± 0.5 MeV (S = 1.9)

$K^*(892)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$K\pi$	∼ 100 %		289
$K^0\gamma$	(2.46±0.21) $\times 10^{-3}$		307
$K^\pm\gamma$	(9.9 ±0.9) $\times 10^{-4}$		309
$K\pi\pi$	< 7 $\times 10^{-4}$	95%	223

$K_1(1270)$

$I(J^P) = \frac{1}{2}(1^+)$

Mass m = 1253 ± 7 MeV [j] (S = 2.2)
Full width Γ = 90 ± 20 MeV [j]

$K_1(1270)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\rho$	(42 ±6) %	†
$K_0^*(1430)\pi$	(28 ±4) %	†
$K^*(892)\pi$	(16 ±5) %	286
$K\omega$	(11.0±2.0) %	†
$K f_0(1370)$	(3.0±2.0) %	†

See Particle Listings for 1 decay modes that have been seen / not seen.

$K_1(1400)$

$I(J^P) = \frac{1}{2}(1^+)$

Mass $m = 1403 \pm 7$ MeV
Full width $\Gamma = 174 \pm 13$ MeV (S = 1.6)

$K_1(1400)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K^*(892)\pi$	(94 ± 6) %	402
$K\rho$	(3.0 ± 3.0) %	293
$K f_0(1370)$	(2.0 ± 2.0) %	†
$K\omega$	(1.0 ± 1.0) %	284

See Particle Listings for 2 decay modes that have been seen / not seen.

$K^*(1410)$

$I(J^P) = \frac{1}{2}(1^-)$

Mass $m = 1414 \pm 15$ MeV (S = 1.3)
Full width $\Gamma = 232 \pm 21$ MeV (S = 1.1)

$K^*(1410)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$K^*(892)\pi$	> 40 %	95%	410
$K\pi$	(6.6 ± 1.3) %		612
$K\rho$	< 7 %	95%	305
γK^0	$< 2.3 \times 10^{-4}$	90%	619

$K_0^*(1430)$ [hh]

$I(J^P) = \frac{1}{2}(0^+)$

Mass $m = 1425 \pm 50$ MeV
Full width $\Gamma = 270 \pm 80$ MeV

$K_0^*(1430)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\pi$	(93 ± 10) %	619
$K\eta$	$(8.6^{+2.7}_{-3.4})$ %	486

See Particle Listings for 1 decay modes that have been seen / not seen.

$K_2^*(1430)$

$I(J^P) = \frac{1}{2}(2^+)$

$K_2^*(1430)^\pm$ mass $m = 1427.3 \pm 1.5$ MeV (S = 1.3)
$K_2^*(1430)^0$ mass $m = 1432.4 \pm 1.3$ MeV
$K_2^*(1430)^\pm$ full width $\Gamma = 100.0 \pm 2.1$ MeV
$K_2^*(1430)^0$ full width $\Gamma = 109 \pm 5$ MeV (S = 1.9)

$K_2^*(1430)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$K\pi$	(49.9 ± 1.2) %		620
$K^*(892)\pi$	(24.7 ± 1.5) %		420
$K^*(892)\pi\pi$	(13.4 ± 2.2) %		373
$K\rho$	(8.7 ± 0.8) %	S=1.2	320
$K\omega$	(2.9 ± 0.8) %		313
$K^+\gamma$	$(2.4\pm0.5) \times 10^{-3}$	S=1.1	628
$K\eta$	$(1.5^{+3.4}_{-1.0}) \times 10^{-3}$	S=1.3	488

$K\omega\pi$	$<$ 7.2	$\times 10^{-4}$	CL=95%	106
$K^0\gamma$	$<$ 9	$\times 10^{-4}$	CL=90%	627

$K^*(1680)$

$I(J^P) = \frac{1}{2}(1^-)$

Mass $m = 1718 \pm 18$ MeV
Full width $\Gamma = 322 \pm 110$ MeV (S = 4.2)

$K^*(1680)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\pi$	(38.7 ± 2.5) %	782
$K\rho$	$(31.4^{+5.0}_{-2.1})$ %	571
$K^*(892)\pi$	$(29.9^{+2.2}_{-5.0})$ %	618

See Particle Listings for 1 decay modes that have been seen / not seen.

$K_2(1770)$ [ii]

$I(J^P) = \frac{1}{2}(2^-)$

Mass $m = 1773 \pm 8$ MeV
Full width $\Gamma = 186 \pm 14$ MeV

$K_2(1770)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\pi\pi$		794

See Particle Listings for 5 decay modes that have been seen / not seen.

$K_3^*(1780)$

$I(J^P) = \frac{1}{2}(3^-)$

Mass $m = 1776 \pm 7$ MeV (S = 1.1)
Full width $\Gamma = 159 \pm 21$ MeV (S = 1.3)

$K_3^*(1780)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$K\rho$	(31 ± 9) %		613
$K^*(892)\pi$	(20 ± 5) %		656
$K\pi$	(18.8 ± 1.0) %		813
$K\eta$	(30 ± 13) %		719
$K_2^*(1430)\pi$	$<$ 16 %	95%	290

$K_2(1820)$ [jj]

$I(J^P) = \frac{1}{2}(2^-)$

Mass $m = 1819 \pm 12$ MeV
Full width $\Gamma = 264 \pm 34$ MeV

$K_4^*(2045)$

$I(J^P) = \frac{1}{2}(4^+)$

Mass $m = 2048^{+8}_{-9}$ MeV (S = 1.1)
Full width $\Gamma = 199^{+27}_{-19}$ MeV

$K_4^*(2045)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\pi$	(9.9 ± 1.2) %	960
$K^*(892)\pi\pi$	(9 ± 5) %	804

$K^*(892)\pi\pi\pi$	(7 ±5) %	770
$\rho K\pi$	(5.7±3.2) %	744
$\omega K\pi$	(5.0±3.0) %	740
$\phi K\pi$	(2.8±1.4) %	597
$\phi K^*(892)$	(1.4±0.7) %	368

CHARMED MESONS ($C = \pm1$)

$D^+ = c\overline{d}$, $D^0 = c\overline{u}$, $\overline{D}^0 = \overline{c}\,u$, $D^- = \overline{c}\,d$, similarly for D^*'s

$D^\pm$

$I(J^P) = \frac{1}{2}(0^-)$

Mass $m = 1869.65 \pm 0.05$ MeV
Mean life $\tau = (1040 \pm 7) \times 10^{-15}$ s
$c\tau = 311.8\ \mu$m

c-quark decays

$\Gamma(c \to \ell^+ \text{anything})/\Gamma(c \to \text{anything}) = 0.096 \pm 0.004$ [kk]
$\Gamma(c \to D^*(2010)^+ \text{anything})/\Gamma(c \to \text{anything}) = 0.255 \pm 0.017$

CP-violation decay-rate asymmetries

$A_{CP}(\mu^\pm\nu) = (8 \pm 8)\%$
$A_{CP}(K^0_L e^\pm\nu) = (-0.6 \pm 1.6)\%$
$A_{CP}(K^0_S\pi^\pm) = (-0.41 \pm 0.09)\%$
$A_{CP}(K^0_L K^\pm)$ in $D^\pm \to K^0_L K^\pm = (-4.2 \pm 3.4) \times 10^{-2}$
$A_{CP}(K^\mp 2\pi^\pm) = (-0.18 \pm 0.16)\%$
$A_{CP}(K^\mp\pi^\pm\pi^\pm\pi^0) = (-0.3 \pm 0.7)\%$
$A_{CP}(K^0_S\pi^\pm\pi^0) = (-0.1 \pm 0.7)\%$
$A_{CP}(K^0_S\pi^\pm\pi^+\pi^-) = (0.0 \pm 1.2)\%$
$A_{CP}(\pi^\pm\pi^0) = (2.4 \pm 1.2)\%$
$A_{CP}(\pi^\pm\eta) = (1.0 \pm 1.5)\%$ (S = 1.4)
$A_{CP}(\pi^\pm\eta'(958)) = (-0.6 \pm 0.7)\%$
$A_{CP}(\overline{K}^0/K^0 K^\pm) = (0.11 \pm 0.17)\%$
$A_{CP}(K^0_S K^\pm) = (-0.01 \pm 0.07)\%$
$A_{CP}(K^0_S K^\pm\pi^0)$ in $D^\pm \to K^0_S K^\pm\pi^0 = (1 \pm 4) \times 10^{-2}$
$A_{CP}(K^0_L K^\pm\pi^0)$ in $D^\pm \to K^0_L K^\pm\pi^0 = (-1 \pm 4) \times 10^{-2}$
$A_{CP}(K^+K^-\pi^\pm) = (0.37 \pm 0.29)\%$
$A_{CP}(K^\pm K^{*0}) = (-0.3 \pm 0.4)\%$
$A_{CP}(\phi\pi^\pm) = (0.01 \pm 0.09)\%$ (S = 1.8)
$A_{CP}(K^\pm K^*_0(1430)^0) = (8^{+7}_{-6})\%$
$A_{CP}(K^\pm K^*_2(1430)^0) = (43^{+20}_{-26})\%$
$A_{CP}(K^\pm K^*_0(700)) = (-12^{+18}_{-13})\%$
$A_{CP}(a_0(1450)^0\pi^\pm) = (-19^{+14}_{-16})\%$
$A_{CP}(\phi(1680)\pi^\pm) = (-9 \pm 26)\%$
$A_{CP}(\pi^+\pi^-\pi^\pm) = (-2 \pm 4)\%$
$A_{CP}(K^0_S K^\pm\pi^+\pi^-) = (-4 \pm 7)\%$
$A_{CP}(K^\pm\pi^0) = (-4 \pm 11)\%$

χ^2 tests of *CP*-violation (*CPV*)

Local *CPV* in $D^\pm \to \pi^+\pi^-\pi^\pm = 78.1\%$
Local *CPV* in $D^\pm \to K^+K^-\pi^\pm = 31\%$

CP violating asymmetries of *P*-odd (*T*-odd) moments

$A_T(K^0_S K^\pm \pi^+ \pi^-) = (-12 \pm 11) \times 10^{-3}$ [ll]

D^+ form factors

$f_+(0)|V_{cs}|$ in $\overline{K}^0 \ell^+ \nu_\ell = 0.719 \pm 0.011$ (S = 1.6)
$r_1 \equiv a_1/a_0$ in $\overline{K}^0 \ell^+ \nu_\ell = -2.13 \pm 0.14$
$r_2 \equiv a_2/a_0$ in $\overline{K}^0 \ell^+ \nu_\ell = -3 \pm 12$ (S = 1.5)
$f_+(0)|V_{cd}|$ in $\pi^0 \ell^+ \nu_\ell = 0.1407 \pm 0.0025$
$r_1 \equiv a_1/a_0$ in $\pi^0 \ell^+ \nu_\ell = -2.00 \pm 0.13$
$r_2 \equiv a_2/a_0$ in $\pi^0 \ell^+ \nu_\ell = -4 \pm 5$
$f_+(0)|V_{cd}|$ in $D^+ \to \eta e^+ \nu_e = (8.3 \pm 0.5) \times 10^{-2}$
$r_1 \equiv a_1/a_0$ in $D^+ \to \eta e^+ \nu_e = -5.3 \pm 2.7$ (S = 1.9)
$r_v \equiv V(0)/A_1(0)$ in $D^+ \to \omega e^+ \nu_e = 1.24 \pm 0.11$
$r_2 \equiv A_2(0)/A_1(0)$ in $D^+ \to \omega e^+ \nu_e = 1.06 \pm 0.16$
$r_v \equiv V(0)/A_1(0)$ in $D^+, D^0 \to \rho e^+ \nu_e = 1.64 \pm 0.10$ (S = 1.2)
$r_2 \equiv A_2(0)/A_1(0)$ in $D^+, D^0 \to \rho e^+ \nu_e = 0.84 \pm 0.06$
$r_v \equiv V(0)/A_1(0)$ in $\overline{K}^*(892)^0 \ell^+ \nu_\ell = 1.49 \pm 0.05$ (S = 2.1)
$r_2 \equiv A_2(0)/A_1(0)$ in $\overline{K}^*(892)^0 \ell^+ \nu_\ell = 0.802 \pm 0.021$
$r_3 \equiv A_3(0)/A_1(0)$ in $\overline{K}^*(892)^0 \ell^+ \nu_\ell = 0.0 \pm 0.4$
Γ_L/Γ_T in $\overline{K}^*(892)^0 \ell^+ \nu_\ell = 1.13 \pm 0.08$
Γ_+/Γ_- in $\overline{K}^*(892)^0 \ell^+ \nu_\ell = 0.22 \pm 0.06$ (S = 1.6)

Most decay modes (other than the semileptonic modes) that involve a neutral K meson are now given as K^0_S modes, not as $\overline{K}^0$ modes. Nearly always it is a K^0_S that is measured, and interference between Cabibbo-allowed and doubly Cabibbo-suppressed modes can invalidate the assumption that $2\,\Gamma(K^0_S) = \Gamma(\overline{K}^0)$.

D^+ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Inclusive modes			
e^+ semileptonic	(16.07 ± 0.30) %		–
μ^+ anything	(17.6 ± 3.2) %		–
K^- anything	(25.7 ± 1.4) %		–
$\overline{K}^0$ anything + K^0 anything	(61 ± 5) %		–
K^+ anything	(5.9 ± 0.8) %		–
$K^*(892)^-$ anything	(6 ± 5) %		–
$\overline{K}^*(892)^0$ anything	(23 ± 5) %		–
$K^*(892)^0$ anything	< 6.6 %	CL=90%	–
η anything	(6.3 ± 0.7) %		–
η' anything	(1.04 ± 0.18) %		–
ϕ anything	(1.12 ± 0.04) %		–
Leptonic and semileptonic modes			
$e^+ \nu_e$	< 8.8 $\times 10^{-6}$	CL=90%	935
$\gamma e^+ \nu_e$	< 3.0 $\times 10^{-5}$	CL=90%	935
$\mu^+ \nu_\mu$	(3.74 ± 0.17) $\times 10^{-4}$		932
$\tau^+ \nu_\tau$	(1.20 ± 0.27) $\times 10^{-3}$		90
$\overline{K}^0 e^+ \nu_e$	(8.73 ± 0.10) %		869
$\overline{K}^0 \mu^+ \nu_\mu$	(8.76 ± 0.19) %		865
$K^- \pi^+ e^+ \nu_e$	(4.02 ± 0.18) %	S=3.2	864
$\overline{K}^*(892)^0 e^+ \nu_e$, $\overline{K}^*(892)^0 \to K^- \pi^+$	(3.77 ± 0.17) %		722
$(K^- \pi^+)_{[0.8–1.0]\mathrm{GeV}}\, e^+ \nu_e$	(3.39 ± 0.09) %		864

$(K^-\pi^+)_{S-wave}\, e^+\nu_e$		(2.28 ± 0.11) $\times 10^{-3}$		–
$\overline{K}^*(1410)^0 e^+\nu_e$, $\overline{K}^*(1410)^0 \to K^-\pi^+$		< 6 $\times 10^{-3}$	CL=90%	–
$\overline{K}^*_2(1430)^0 e^+\nu_e$, $\overline{K}^*_2(1430)^0 \to K^-\pi^+$		< 5 $\times 10^{-4}$	CL=90%	–
$K^-\pi^+ e^+\nu_e$ nonresonant		< 7 $\times 10^{-3}$	CL=90%	864
$\overline{K}^*(892)^0 e^+\nu_e$		(5.40 ± 0.10) %	S=1.1	722
$K^-\pi^+\mu^+\nu_\mu$		(3.65 ± 0.34) %		851
$\overline{K}^*(892)^0\mu^+\nu_\mu$, $\overline{K}^*(892)^0 \to K^-\pi^+$		(3.52 ± 0.10) %		717
$K^-\pi^+\mu^+\nu_\mu$ nonresonant		(1.9 ± 0.5) $\times 10^{-3}$		851
$\overline{K}^*(892)^0\mu^+\nu_\mu$		(5.27 ± 0.15) %		717
$K^-\pi^+\pi^0\mu^+\nu_\mu$		< 1.5 $\times 10^{-3}$	CL=90%	825
$\overline{K}_1(1270)^0 e^+\nu_e$, $\overline{K}^0_1 \to K^-\pi^+\pi^0$		(1.06 ± 0.15) $\times 10^{-3}$		–
$\overline{K}^*_0(1430)^0\mu^+\nu_\mu$		< 2.3 $\times 10^{-4}$	CL=90%	380
$\overline{K}^*(1680)^0\mu^+\nu_\mu$		< 1.5 $\times 10^{-3}$	CL=90%	105
$\pi^0 e^+\nu_e$		(3.72 ± 0.17) $\times 10^{-3}$	S=2.0	930
$\pi^0\mu^+\nu_\mu$		(3.50 ± 0.15) $\times 10^{-3}$		927
$\eta e^+\nu_e$		(1.11 ± 0.07) $\times 10^{-3}$		855
$\pi^-\pi^+ e^+\nu_e$		(2.45 ± 0.10) $\times 10^{-3}$		924
$f_0(500)^0 e^+\nu_e$, $f_0(500)^0 \to \pi^+\pi^-$		(6.3 ± 0.5) $\times 10^{-4}$		–
$\rho^0 e^+\nu_e$		(2.18 $^{+0.17}_{-0.25}$) $\times 10^{-3}$		774
$\rho^0\mu^+\nu_\mu$		(2.4 ± 0.4) $\times 10^{-3}$		770
$\omega e^+\nu_e$		(1.69 ± 0.11) $\times 10^{-3}$		771
$\eta'(958) e^+\nu_e$		(2.0 ± 0.4) $\times 10^{-4}$		690
$a(980)^0 e^+\nu_e$, $a(980)^0 \to \eta\pi^0$		(1.7 $^{+0.8}_{-0.7}$) $\times 10^{-4}$		–
$\phi e^+\nu_e$		< 1.3 $\times 10^{-5}$	CL=90%	657
$D^0 e^+\nu_e$		< 1.0 $\times 10^{-4}$	CL=90%	5

Hadronic modes with a $\overline{K}$ or $\overline{K}K\overline{K}$

$K^0_S\pi^+$		(1.562 ± 0.031) %	S=1.7	863
$K^0_L\pi^+$		(1.46 ± 0.05) %		863
$K^-2\pi^+$	[nn]	(9.38 ± 0.16) %	S=1.6	846
$(K^-\pi^+)_{S-\mathrm{wave}}\pi^+$		(7.52 ± 0.17) %		846
$\overline{K}^*_0(1430)^0\pi^+$, $\overline{K}^*_0(1430)^0 \to K^-\pi^+$	[oo]	(1.25 ± 0.06) %		382
$\overline{K}^*(892)^0\pi^+$, $\overline{K}^*(892)^0 \to K^-\pi^+$		(1.04 ± 0.12) %		714
$\overline{K}^*_2(1430)^0\pi^+$, $\overline{K}^*_2(1430)^0 \to K^-\pi^+$	[oo]	(2.3 ± 0.7) $\times 10^{-4}$		371
$\overline{K}^*(1680)^0\pi^+$, $\overline{K}^*(1680)^0 \to K^-\pi^+$	[oo]	(2.2 ± 1.1) $\times 10^{-4}$		58
$K^-(2\pi^+)_{I=2}$		(1.45 ± 0.26) %		–
$K^0_S\pi^+\pi^0$	[nn]	(7.36 ± 0.21) %		845
$K^0_S\rho^+$		(6.14 $^{+0.60}_{-0.35}$) %		677
$K^0_S\rho(1450)^+$, $\rho^+ \to \pi^+\pi^0$		(1.5 $^{+1.2}_{-1.4}$) $\times 10^{-3}$		–
$\overline{K}^*(892)^0\pi^+$, $\overline{K}^*(892)^0 \to K^0_S\pi^0$		(2.64 ± 0.32) $\times 10^{-3}$		714
$\overline{K}^*_0(1430)^0\pi^+$, $\overline{K}^{*0}_0 \to K^0_S\pi^0$		(2.7 ± 0.9) $\times 10^{-3}$		–

$\overline{K}_0^*(1680)^0\pi^+$, $\overline{K}_0^{*0} \to K_S^0\pi^0$		$(10\ ^{+\ 7}_{-10})\times 10^{-4}$		–
$\overline{\kappa}^0\pi^+$, $\overline{\kappa}^0 \to K_S^0\pi^0$		$(\ 6\ ^{+\ 5}_{-\ 4})\times 10^{-3}$		–
$K_S^0\pi^+\pi^0$ nonresonant		$(\ 3\ \pm\ 4\ )\times 10^{-3}$		845
$K_S^0\pi^+\pi^0$ nonresonant and $\overline{\kappa}^0\pi^+$		$(\ 1.37\ ^{+\ 0.21}_{-\ 0.40})$ %		–
$(K_S^0\pi^0)_{S-\text{wave}}\pi^+$		$(\ 1.27\ ^{+\ 0.27}_{-\ 0.33})$ %		845
$K_S^0\pi^+\eta'(958)$		$(\ 1.90\ \pm\ 0.21\ )\times 10^{-3}$		481
$K^-2\pi^+\pi^0$	[pp]	$(\ 6.25\ \pm\ 0.18\ )$ %		816
$K_S^0 2\pi^+\pi^-$	[pp]	$(\ 3.10\ \pm\ 0.09\ )$ %		814
$K^-3\pi^+\pi^-$	[nn]	$(\ 5.7\ \pm\ 0.5\ )\times 10^{-3}$	S=1.1	772
$\overline{K}^*(892)^0 2\pi^+\pi^-$, $\overline{K}^*(892)^0 \to K^-\pi^+$		$(\ 1.2\ \pm\ 0.4\ )\times 10^{-3}$		645
$\overline{K}^*(892)^0\rho^0\pi^+$, $\overline{K}^*(892)^0 \to K^-\pi^+$		$(\ 2.3\ \pm\ 0.4\ )\times 10^{-3}$		239
$\overline{K}^*(892)^0 a_1(1260)^+$	[qq]	$(\ 9.3\ \pm\ 1.9\ )\times 10^{-3}$		†
$K^-\rho^0 2\pi^+$		$(\ 1.72\ \pm\ 0.28\ )\times 10^{-3}$		524
$K^-3\pi^+\pi^-$ nonresonant		$(\ 4.0\ \pm\ 2.9\ )\times 10^{-4}$		772
$K^+2K_S^0$		$(\ 2.54\ \pm\ 0.13\ )\times 10^{-3}$		545
$K^+K^-K_S^0\pi^+$		$(\ 2.4\ \pm\ 0.5\ )\times 10^{-4}$		436
Pionic modes				
$\pi^+\pi^0$		$(\ 1.247\pm\ 0.033)\times 10^{-3}$		925
$2\pi^+\pi^-$		$(\ 3.27\ \pm\ 0.18\ )\times 10^{-3}$		909
$\rho^0\pi^+$		$(\ 8.3\ \pm\ 1.5\ )\times 10^{-4}$		767
$\pi^+(\pi^+\pi^-)_{S-\text{wave}}$		$(\ 1.83\ \pm\ 0.16\ )\times 10^{-3}$		909
$\sigma\pi^+$, $\sigma \to \pi^+\pi^-$		$(\ 1.38\ \pm\ 0.12\ )\times 10^{-3}$		–
$f_0(980)\pi^+$, $f_0(980) \to \pi^+\pi^-$		$(\ 1.56\ \pm\ 0.33\ )\times 10^{-4}$		669
$f_0(1370)\pi^+$, $f_0(1370) \to \pi^+\pi^-$		$(\ 8\ \pm\ 4\ )\times 10^{-5}$		–
$f_2(1270)\pi^+$, $f_2(1270) \to \pi^+\pi^-$		$(\ 5.0\ \pm\ 0.9\ )\times 10^{-4}$		485
$\rho(1450)^0\pi^+$, $\rho(1450)^0 \to \pi^+\pi^-$		$< 8 \times 10^{-5}$	CL=95%	338
$f_0(1500)\pi^+$, $f_0(1500) \to \pi^+\pi^-$		$(\ 1.1\ \pm\ 0.4\ )\times 10^{-4}$		–
$f_0(1710)\pi^+$, $f_0(1710) \to \pi^+\pi^-$		$< 5 \times 10^{-5}$	CL=95%	–
$f_0(1790)\pi^+$, $f_0(1790) \to \pi^+\pi^-$		$< 7 \times 10^{-5}$	CL=95%	–
$(\pi^+\pi^+)_{S-\text{wave}}\pi^-$		$< 1.2 \times 10^{-4}$	CL=95%	909
$2\pi^+\pi^-$ nonresonant		$< 1.1 \times 10^{-4}$	CL=95%	909
$\pi^+2\pi^0$		$(\ 4.7\ \pm\ 0.4\ )\times 10^{-3}$		910
$2\pi^+\pi^-\pi^0$		$(\ 1.16\ \pm\ 0.08\ )$ %		883
$3\pi^+2\pi^-$		$(\ 1.66\ \pm\ 0.16\ )\times 10^{-3}$	S=1.1	845
$\eta\pi^+$		$(\ 3.77\ \pm\ 0.09\ )\times 10^{-3}$		848
$\eta\pi^+\pi^0$		$(\ 1.38\ \pm\ 0.35\ )\times 10^{-3}$		831
$\omega\pi^+$		$(\ 2.8\ \pm\ 0.6\ )\times 10^{-4}$		764
$\eta'(958)\pi^+$		$(\ 4.97\ \pm\ 0.19\ )\times 10^{-3}$		681
$\eta'(958)\pi^+\pi^0$		$(\ 1.6\ \pm\ 0.5\ )\times 10^{-3}$		654
Hadronic modes with a $K\overline{K}$ pair				
$K^+K_S^0$		$(\ 3.04\ \pm\ 0.09\ )\times 10^{-3}$	S=2.2	793
$K_L^0K^+$		$(\ 3.21\ \pm\ 0.16\ )\times 10^{-3}$		793

$K^0_S K^+ \pi^0$		$(5.07 \pm 0.30) \times 10^{-3}$		744
$K^0_L K^+ \pi^0$		$(5.24 \pm 0.31) \times 10^{-3}$		744
$K^+ K^- \pi^+$	[nn]	$(9.68 \pm 0.18) \times 10^{-3}$		744
$\phi \pi^+$		$(5.70 \pm 0.14) \times 10^{-3}$		647
$\phi \pi^+ , \phi \to K^+ K^-$		$(2.69 {}^{+0.07}_{-0.08}) \times 10^{-3}$		647
$K^+ \overline{K}^*(892)^0 , \overline{K}^*(892)^0 \to K^- \pi^+$		$(2.49 {}^{+0.08}_{-0.13}) \times 10^{-3}$		613
$K^+ \overline{K}^*_0(1430)^0 , \overline{K}^*_0(1430)^0 \to K^- \pi^+$		$(1.82 \pm 0.35) \times 10^{-3}$		–
$K^+ \overline{K}^*_2(1430)^0 , \overline{K}^*_2 \to K^- \pi^+$		$(1.6 {}^{+1.2}_{-0.8}) \times 10^{-4}$		–
$K^+ \overline{K}^*_0(700) , \overline{K}^*_0 \to K^- \pi^+$		$(6.8 {}^{+3.5}_{-2.1}) \times 10^{-4}$		–
$a_0(1450)^0 \pi^+ , a^0_0 \to K^+ K^-$		$(4.5 {}^{+7.0}_{-1.8}) \times 10^{-4}$		–
$\phi(1680) \pi^+ , \phi \to K^+ K^-$		$(4.9 {}^{+4.0}_{-1.9}) \times 10^{-5}$		–
$K^0_S K^0_S \pi^+$		$(2.70 \pm 0.13) \times 10^{-3}$		741
$K^+ K^0_S \pi^+ \pi^-$		$(1.74 \pm 0.18) \times 10^{-3}$		678
$K^0_S K^- 2\pi^+$		$(2.38 \pm 0.17) \times 10^{-3}$		678
$K^+ K^- 2\pi^+ \pi^-$		$(2.3 \pm 1.2) \times 10^{-4}$		601

A few poorly measured branching fractions:

$\phi \pi^+ \pi^0$		(2.3 ± 1.0) %		619
$\phi \rho^+$		< 1.5 %	CL=90%	260
$K^+ K^- \pi^+ \pi^0$ non-ϕ		$(1.5 {}^{+0.7}_{-0.6})$ %		682
$K^*(892)^+ K^0_S$		(1.7 ± 0.8) %		612

Doubly Cabibbo-suppressed modes

$K^+ \pi^0$		$(2.08 \pm 0.21) \times 10^{-4}$	S=1.4	864
$K^+ \eta$		$(1.25 \pm 0.16) \times 10^{-4}$	S=1.1	776
$K^+ \eta'(958)$		$(1.85 \pm 0.20) \times 10^{-4}$		571
$K^+ \pi^+ \pi^-$		$(4.91 \pm 0.09) \times 10^{-4}$		846
$K^+ \rho^0$		$(1.9 \pm 0.5) \times 10^{-4}$		679
$K^*(892)^0 \pi^+ , K^*(892)^0 \to K^+ \pi^-$		$(2.3 \pm 0.4) \times 10^{-4}$		714
$K^+ f_0(980) , f_0(980) \to \pi^+ \pi^-$		$(4.4 \pm 2.6) \times 10^{-5}$		–
$K^*_2(1430)^0 \pi^+ , K^*_2(1430)^0 \to K^+ \pi^-$		$(3.9 \pm 2.7) \times 10^{-5}$		–
$2K^+ K^-$		$(6.14 \pm 0.11) \times 10^{-5}$		550
$\phi(1020)^0 K^+$		$< 2.1 \times 10^{-5}$	CL=90%	–
$K^+ \phi(1020) , \phi \to K^+ K^-$		$(4.4 \pm 0.6) \times 10^{-6}$		–
$K^+ (K^+ K^-)_{S-wave}$		$(5.77 \pm 0.12) \times 10^{-5}$		550

$\Delta C = 1$ weak neutral current (*C1*) modes, or Lepton Family number (*LF*) or Lepton number (*L*) violating modes

$\pi^+ e^+ e^-$	C1	$< 1.1 \times 10^{-6}$	CL=90%	930
$\pi^+ \pi^0 e^+ e^-$		$< 1.4 \times 10^{-5}$	CL=90%	925
$\pi^+ \phi , \phi \to e^+ e^-$	[rr]	$(1.7 {}^{+1.4}_{-0.9}) \times 10^{-6}$		–
$\pi^+ \mu^+ \mu^-$	C1	$< 7.3 \times 10^{-8}$	CL=90%	918
$\pi^+ \phi , \phi \to \mu^+ \mu^-$	[rr]	$(1.8 \pm 0.8) \times 10^{-6}$		–
$\rho^+ \mu^+ \mu^-$	C1	$< 5.6 \times 10^{-4}$	CL=90%	757
$K^+ e^+ e^-$	[ss]	$< 1.0 \times 10^{-6}$	CL=90%	870
$K^+ \pi^0 e^+ e^-$		$< 1.5 \times 10^{-5}$	CL=90%	864
$K^0_S \pi^+ e^+ e^-$		$< 2.6 \times 10^{-5}$	CL=90%	–

$K^0_S K^+ e^+ e^-$			< 1.1	$\times 10^{-5}$	CL=90%	–
$K^+ \mu^+ \mu^-$		[ss]	< 4.3	$\times 10^{-6}$	CL=90%	856
$\pi^+ e^+ \mu^-$	LF		< 2.9	$\times 10^{-6}$	CL=90%	927
$\pi^+ e^- \mu^+$	LF		< 3.6	$\times 10^{-6}$	CL=90%	927
$K^+ e^+ \mu^-$	LF		< 1.2	$\times 10^{-6}$	CL=90%	866
$K^+ e^- \mu^+$	LF		< 2.8	$\times 10^{-6}$	CL=90%	866
$\pi^- 2e^+$	L		< 1.1	$\times 10^{-6}$	CL=90%	930
$\pi^- 2\mu^+$	L		< 2.2	$\times 10^{-8}$	CL=90%	918
$\pi^- e^+ \mu^+$	L		< 2.0	$\times 10^{-6}$	CL=90%	927
$\rho^- 2\mu^+$	L		< 5.6	$\times 10^{-4}$	CL=90%	757
$K^- 2e^+$	L		< 9	$\times 10^{-7}$	CL=90%	870
$K^0_S \pi^- 2e^+$			< 3.3	$\times 10^{-6}$	CL=90%	863
$K^- \pi^0 2e^+$			< 8.5	$\times 10^{-6}$	CL=90%	864
$K^- 2\mu^+$	L		< 1.0	$\times 10^{-5}$	CL=90%	856
$K^- e^+ \mu^+$	L		< 1.9	$\times 10^{-6}$	CL=90%	866
$K^*(892)^- 2\mu^+$	L		< 8.5	$\times 10^{-4}$	CL=90%	703

See Particle Listings for 2 decay modes that have been seen / not seen.

D^0

$I(J^P) = \frac{1}{2}(0^-)$

Mass $m = 1864.83 \pm 0.05$ MeV

$m_{D^\pm} - m_{D^0} = 4.822 \pm 0.015$ MeV

Mean life $\tau = (410.1 \pm 1.5) \times 10^{-15}$ s

$c\tau = 122.9\ \mu$m

Mixing and related parameters

$\left|m_{D^0_1} - m_{D^0_2}\right| = (0.95^{+0.41}_{-0.44}) \times 10^{10}\ \hbar\ \mathrm{s}^{-1}$

$(\Gamma_{D^0_1} - \Gamma_{D^0_2})/\Gamma = 2y = (1.29^{+0.14}_{-0.18}) \times 10^{-2}$

$\left|q/p\right| = 0.92^{+0.12}_{-0.09}$

$A_\Gamma = (-0.125 \pm 0.526) \times 10^{-3}$

$\phi^{K^0_S \pi\pi} = -0.09^{+0.10}_{-0.13}$

$K^+\pi^-$ relative strong phase: $\cos\delta = 0.97 \pm 0.11$

$K^-\pi^+\pi^0$ coherence factor $R_{K\pi\pi^0} = 0.82 \pm 0.06$

$K^-\pi^+\pi^0$ average relative strong phase $\delta^{K\pi\pi^0} = (199 \pm 14)^\circ$

$K^-\pi^- 2\pi^+$ coherence factor $R_{K3\pi} = 0.53^{+0.18}_{-0.21}$

$K^-\pi^- 2\pi^+$ average relative strong phase $\delta^{K3\pi} = (125^{+22}_{-14})^\circ$

$D^0 \to K^-\pi^- 2\pi^+$, $R_{K3\pi}$ (y $\cos\delta^{K3\pi}$ − x $\sin\delta^{K3\pi}$) $= (-3.0 \pm 0.7) \times 10^{-3}$ TeV^{-1}

$K^0_S K^+\pi^-$ coherence factor $R_{K^0_S K\pi} = 0.70 \pm 0.08$

$K^0_S K^+\pi^-$ average relative strong phase $\delta^{K^0_S K\pi} = (0 \pm 16)^\circ$

$K^* K$ coherence factor $R_{K^* K} = 0.94 \pm 0.12$

$K^* K$ average relative strong phase $\delta^{K^* K} = (-17 \pm 18)^\circ$

***CP*-violation decay-rate asymmetries (labeled by the D^0 decay)**

$A_{CP}(K^+K^-) = (-0.07 \pm 0.11)\%$

$A_{CP}(2K^0_S) = (0.4 \pm 1.4)\%$

$A_{CP}(\pi^+\pi^-) = (0.13 \pm 0.14)\%$

$A_{CP}(\pi^0\pi^0) = (0.0 \pm 0.6)\%$

$A_{CP}(\rho\gamma) = (6 \pm 15) \times 10^{-2}$

$A_{CP}(\phi\gamma) = (-9 \pm 7) \times 10^{-2}$

$A_{CP}(\overline{K}^*(892)^0\gamma) = (-0.3 \pm 2.0) \times 10^{-2}$

$A_{CP}(\pi^+\pi^-\pi^0) = (0.3 \pm 0.4)\%$
$A_{CP}(\rho(770)^+\pi^- \to \pi^+\pi^-\pi^0) = (1.2 \pm 0.9)\%$ [tt]
$A_{CP}(\rho(770)^0\pi^0 \to \pi^+\pi^-\pi^0) = (-3.1 \pm 3.0)\%$ [tt]
$A_{CP}(\rho(770)^-\pi^+ \to \pi^+\pi^-\pi^0) = (-1.0 \pm 1.7)\%$ [tt]
$A_{CP}(\rho(1450)^+\pi^- \to \pi^+\pi^-\pi^0) = (0 \pm 70)\%$ [tt]
$A_{CP}(\rho(1450)^0\pi^0 \to \pi^+\pi^-\pi^0) = (-20 \pm 40)\%$ [tt]
$A_{CP}(\rho(1450)^-\pi^+ \to \pi^+\pi^-\pi^0) = (6 \pm 9)\%$ [tt]
$A_{CP}(\rho(1700)^+\pi^- \to \pi^+\pi^-\pi^0) = (-5 \pm 14)\%$ [tt]
$A_{CP}(\rho(1700)^0\pi^0 \to \pi^+\pi^-\pi^0) = (13 \pm 9)\%$ [tt]
$A_{CP}(\rho(1700)^-\pi^+ \to \pi^+\pi^-\pi^0) = (8 \pm 11)\%$ [tt]
$A_{CP}(f_0(980)\pi^0 \to \pi^+\pi^-\pi^0) = (0 \pm 35)\%$ [tt]
$A_{CP}(f_0(1370)\pi^0 \to \pi^+\pi^-\pi^0) = (25 \pm 18)\%$ [tt]
$A_{CP}(f_0(1500)\pi^0 \to \pi^+\pi^-\pi^0) = (0 \pm 18)\%$ [tt]
$A_{CP}(f_0(1710)\pi^0 \to \pi^+\pi^-\pi^0) = (0 \pm 24)\%$ [tt]
$A_{CP}(f_2(1270)\pi^0 \to \pi^+\pi^-\pi^0) = (-4 \pm 6)\%$ [tt]
$A_{CP}(\sigma(400)\pi^0 \to \pi^+\pi^-\pi^0) = (6 \pm 8)\%$ [tt]
$A_{CP}(\text{nonresonant } \pi^+\pi^-\pi^0) = (-13 \pm 23)\%$ [tt]
$A_{CP}(a_1(1260)^+\pi^- \to 2\pi^+2\pi^-) = (5 \pm 6)\%$
$A_{CP}(a_1(1260)^-\pi^+ \to 2\pi^+2\pi^-) = (14 \pm 18)\%$
$A_{CP}(\pi(1300)^+\pi^- \to 2\pi^+2\pi^-) = (-2 \pm 15)\%$
$A_{CP}(\pi(1300)^-\pi^+ \to 2\pi^+2\pi^-) = (-6 \pm 30)\%$
$A_{CP}(a_1(1640)^+\pi^- \to 2\pi^+2\pi^-) = (9 \pm 26)\%$
$A_{CP}(\pi_2(1670)^+\pi^- \to 2\pi^+2\pi^-) = (7 \pm 18)\%$
$A_{CP}(\sigma f_0(1370) \to 2\pi^+2\pi^-) = (-15 \pm 19)\%$
$A_{CP}(\sigma\rho(770)^0 \to 2\pi^+2\pi^-) = (3 \pm 27)\%$
$A_{CP}(2\rho(770)^0 \to 2\pi^+2\pi^-) = (-6 \pm 6)\%$
$A_{CP}(2f_2(1270) \to 2\pi^+2\pi^-) = (-28 \pm 24)\%$
$A_{CP}(K^+K^-\pi^0) = (-1.0 \pm 1.7)\%$
$A_{CP}(K^*(892)^+K^- \to K^+K^-\pi^0) = (-0.9 \pm 1.3)\%$ [tt]
$A_{CP}(K^*(1410)^+K^- \to K^+K^-\pi^0) = (-21 \pm 24)\%$ [tt]
$A_{CP}((K^+\pi^0)_{S-wave}K^- \to K^+K^-\pi^0) = (7 \pm 15)\%$ [tt]
$A_{CP}(\phi(1020)\pi^0 \to K^+K^-\pi^0) = (1.1 \pm 2.2)\%$ [tt]
$A_{CP}(f_0(980)\pi^0 \to K^+K^-\pi^0) = (-3 \pm 19)\%$ [tt]
$A_{CP}(a_0(980)^0\pi^0 \to K^+K^-\pi^0) = (-5 \pm 16)\%$ [tt]
$A_{CP}(f'_2(1525)\pi^0 \to K^+K^-\pi^0) = (0 \pm 160)\%$ [tt]
$A_{CP}(K^*(892)^-K^+ \to K^+K^-\pi^0) = (-5 \pm 4)\%$ [tt]
$A_{CP}(K^*(1410)^-K^+ \to K^+K^-\pi^0) = (-17 \pm 29)\%$ [tt]
$A_{CP}((K^-\pi^0)_{S-wave}K^+ \to K^+K^-\pi^0) = (-10 \pm 40)\%$ [tt]
$A_{CP}(K^0_S\pi^0) = (-0.20 \pm 0.17)\%$
$A_{CP}(K^0_S\eta) = (0.5 \pm 0.5)\%$
$A_{CP}(K^0_S\eta') = (1.0 \pm 0.7)\%$
$A_{CP}(K^0_S\phi) = (-3 \pm 9)\%$
$A_{CP}(K^-\pi^+) = (0.2 \pm 0.5)\%$
$A_{CP}(K^+\pi^-) = (-0.9 \pm 1.4)\%$
$A_{CP}(D_{CP(\pm 1)} \to K^\mp\pi^\pm) = (12.7 \pm 1.5)\%$
$A_{CP}(K^-\pi^+\pi^0) = (0.1 \pm 0.5)\%$
$A_{CP}(K^+\pi^-\pi^0) = (0 \pm 5)\%$
$A_{CP}(K^0_S\pi^+\pi^-) = (-0.1 \pm 0.8)\%$
$A_{CP}(K^*(892)^-\pi^+ \to K^0_S\pi^+\pi^-) = (0.4 \pm 0.5)\%$
$A_{CP}(K^*(892)^+\pi^- \to K^0_S\pi^+\pi^-) = (1 \pm 6)\%$
$A_{CP}(\overline{K}^0\rho^0 \to K^0_S\pi^+\pi^-) = (-0.1 \pm 0.5)\%$

$A_{CP}(\overline{K}^0\omega \to K_S^0\pi^+\pi^-) = (-13 \pm 7)\%$
$A_{CP}(\overline{K}^0 f_0(980) \to K_S^0\pi^+\pi^-) = (-0.4 \pm 2.7)\%$
$A_{CP}(\overline{K}^0 f_2(1270) \to K_S^0\pi^+\pi^-) = (-4 \pm 5)\%$
$A_{CP}(\overline{K}^0 f_0(1370) \to K_S^0\pi^+\pi^-) = (-1 \pm 9)\%$
$A_{CP}(\overline{K}^0 \rho^0(1450) \to K_S^0\pi^+\pi^-) = (-4 \pm 10)\%$
$A_{CP}(\overline{K}^0 f_0(600) \to K_S^0\pi^+\pi^-) = (-3 \pm 5)\%$
$A_{CP}(K^*(1410)^-\pi^+ \to K_S^0\pi^+\pi^-) = (-2 \pm 9)\%$
$A_{CP}(K_0^*(1430)^-\pi^+ \to K_S^0\pi^+\pi^-) = (4 \pm 4)\%$
$A_{CP}(K_0^*(1430)^+\pi^- \to K_S^0\pi^+\pi^-) = (12 \pm 15)\%$
$A_{CP}(K_2^*(1430)^-\pi^+ \to K_S^0\pi^+\pi^-) = (3 \pm 6)\%$
$A_{CP}(K_2^*(1430)^+\pi^- \to K_S^0\pi^+\pi^-) = (-10 \pm 32)\%$
$A_{CP}(K^-\pi^+\pi^+\pi^-) = (0.2 \pm 0.5)\%$
$A_{CP}(K^+\pi^-\pi^+\pi^-) = (-2 \pm 4)\%$
$A_{CP}(K^+K^-\pi^+\pi^-) = (1.3 \pm 1.7)\%$
$A_{CP}(K_1^*(1270)^+K^- \to K^+K^-\pi^+\pi^-) = (-2.3 \pm 1.7)\%$
$A_{CP}(K_1^*(1270)^+K^- \to K^{*0}\pi^+K^-) = (-1 \pm 10)\%$
$A_{CP}(K_1^*(1270)^-K^+ \to \overline{K}^{*0}\pi^-K^+) = (-10 \pm 32)\%$
$A_{CP}(K_1^*(1270)^-K^+ \to K^+K^-\pi^+\pi^-) = (1.7 \pm 3.5)\%$
$A_{CP}(K_1^*(1270)^+K^- \to \rho^0K^+K^-) = (-7 \pm 17)\%$
$A_{CP}(K_1^*(1270)^-K^+ \to \rho^0K^-K^+) = (10 \pm 13)\%$
$A_{CP}(K_1(1400)^+K^- \to K^+K^-\pi^+\pi^-) = (-4.4 \pm 2.1)\%$
$A_{CP}(K^*(1410)^+K^- \to K^{*0}\pi^+K^-) = (-20 \pm 17)\%$
$A_{CP}(K^*(1410)^-K^+ \to \overline{K}^{*0}\pi^-K^+) = (-1 \pm 14)\%$
$A_{CP}(K^*(1680)^+K^- \to K^+K^-\pi^+\pi^-) = (-17 \pm 29)\%$
$A_{CP}(K^{*0}\overline{K}^{*0})$ in D^0, $\overline{D}^0 \to K^{*0}\overline{K}^{*0} = (-5 \pm 14)\%$
$A_{CP}(K^{*0}\overline{K}^{*0}$ S-wave$) = (-3.9 \pm 2.2)\%$
$A_{CP}(\phi\rho^0)$ in D^0, $\overline{D}^0 \to \phi\rho^0 = (1 \pm 9)\%$
$A_{CP}(\phi\rho^0$ S-wave$) = (-3 \pm 5)\%$
$A_{CP}(\phi\rho^0$ D-wave$) = (-37 \pm 19)\%$
$A_{CP}(\phi(\pi^+\pi^-)_{S-wave}) = (6 \pm 6)\%$
$A_{CP}(K^*(892)^0(K^-\pi^+)_{S-wave}) = (-10 \pm 40)\%$
$A_{CP}(K^+K^-\pi^+\pi^-$ non-resonant$) = (8 \pm 20)\%$
$A_{CP}((K^-\pi^+)_{P-wave}\,(K^+\pi^-)_{S-wave}) = (3 \pm 11)\%$
$A_{CP}(K^+K^-\mu^+\mu^-)$ in D^0, $\overline{D}^0 \to K^+K^-\mu^+\mu^- = (0 \pm 11)\%$
$A_{CP}(\pi^+\pi^-\mu^+\mu^-)$ in D^0, $\overline{D}^0 \to \pi^+\pi^-\mu^+\mu^- = (5 \pm 4)\%$

CP-even fractions (labeled by the D^0 decay)

CP-even fraction in $D^0 \to \pi^+\pi^-\pi^0$ decays $= (97.3 \pm 1.7)\%$
CP-even fraction in $D^0 \to K^+K^-\pi^0$ decays $= (73 \pm 6)\%$
CP-even fraction in $D^0 \to \pi^+\pi^-\pi^+\pi^-$ decays $= (76.9 \pm 2.3)\%$
CP-even fraction in $D^0 \to K_S^0\pi^+\pi^-\pi^0$ decays $= (23.8 \pm 1.7)\%$
CP-even fraction in $D^0 \to K^+K^-\pi^+\pi^-$ decays $= (75 \pm 4)\%$

CP-violation asymmetry difference

$\Delta A_{CP} = A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-) = (-0.154 \pm 0.029)\%$

χ^2 tests of CP-violation (CPV) p-values

Local CPV in D^0, $\overline{D}^0 \to \pi^+\pi^-\pi^0 = 4.9\%$
Local CPV in D^0, $\overline{D}^0 \to \pi^+\pi^-\pi^+\pi^- = (0.6 \pm 0.2)\%$
Local CPV in D^0, $\overline{D}^0 \to K_S^0\pi^+\pi^- = 96\%$
Local CPV in D^0, $\overline{D}^0 \to K^+K^-\pi^0 = 16.6\%$
Local CPV in D^0, $\overline{D}^0 \to K^+K^-\pi^+\pi^- = 9.1\%$

T-violation decay-rate asymmetry

$A_T(K^+K^-\pi^+\pi^-) = (2.9 \pm 2.2) \times 10^{-3}$ [ll]

$A_{\text{Tviol}}(K_S\pi^+\pi^-\pi^0)$ in D^0, $\overline{D}^0 \rightarrow K_S\pi^+\pi^-\pi^0 = (-0.3^{+1.4}_{-1.6}) \times 10^{-3}$

CPT-violation decay-rate asymmetry

$A_{CPT}(K^\mp\pi^\pm) = 0.008 \pm 0.008$

Form factors

$r_V \equiv V(0)/A_1(0)$ in $D^0 \rightarrow K^*(892)^-\ell^+\nu_\ell = 1.46 \pm 0.07$

$r_2 \equiv A_2(0)/A_1(0)$ in $D^0 \rightarrow K^*(892)^-\ell^+\nu_\ell = 0.68 \pm 0.06$

$f_+(0)$ in $D^0 \rightarrow K^-\ell^+\nu_\ell = 0.736 \pm 0.004$

$f_+(0)|V_{cs}|$ in $D^0 \rightarrow K^-\ell^+\nu_\ell = 0.7166 \pm 0.0030$

$r_1 \equiv a_1/a_0$ in $D^0 \rightarrow K^-\ell^+\nu_\ell = -2.40 \pm 0.16$

$r_2 \equiv a_2/a_0$ in $D^0 \rightarrow K^-\ell^+\nu_\ell = 5 \pm 4$

$f_+(0)$ in $D^0 \rightarrow \pi^-\ell^+\nu_\ell = 0.637 \pm 0.009$

$f_+(0)|V_{cd}|$ in $D^0 \rightarrow \pi^-\ell^+\nu_\ell = 0.1436 \pm 0.0026$ (S = 1.5)

$r_1 \equiv a_1/a_0$ in $D^0 \rightarrow \pi^-\ell^+\nu_\ell = -1.97 \pm 0.28$ (S = 1.4)

$r_2 \equiv a_1/a_0$ in $D^0 \rightarrow \pi^-\ell^+\nu_\ell = -0.2 \pm 2.2$ (S = 1.7)

Most decay modes (other than the semileptonic modes) that involve a neutral K meson are now given as K^0_S modes, not as $\overline{K}^0$ modes. Nearly always it is a K^0_S that is measured, and interference between Cabibbo-allowed and doubly Cabibbo-suppressed modes can invalidate the assumption that $2\,\Gamma(K^0_S) = \Gamma(\overline{K}^0)$.

D^0 DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Topological modes				
0-prongs	[uu]	(15 ± 6) %		–
2-prongs		(71 ± 6) %		–
4-prongs	[vv]	(14.6 ± 0.5) %		–
6-prongs	[xx]	$(6.5 \pm 1.3) \times 10^{-4}$		–
Inclusive modes				
e^+ anything	[yy]	(6.49 ± 0.11) %		–
μ^+ anything		(6.8 ± 0.6) %		–
K^- anything		(54.7 ± 2.8) %	S=1.3	–
$\overline{K}^0$ anything + K^0 anything		(47 ± 4) %		–
K^+ anything		(3.4 ± 0.4) %		–
$K^*(892)^-$ anything		(15 ± 9) %		–
$\overline{K}^*(892)^0$ anything		(9 ± 4) %		–
$K^*(892)^+$ anything		< 3.6 %	CL=90%	–
$K^*(892)^0$ anything		(2.8 ± 1.3) %		–
η anything		(9.5 ± 0.9) %		–
η' anything		(2.48 ± 0.27) %		–
ϕ anything		(1.08 ± 0.04) %		–
invisibles		$< 9.4 \times 10^{-5}$	CL=90%	–
Semileptonic modes				
$K^-e^+\nu_e$		(3.542 ± 0.035) %	S=1.3	867
$K^-\mu^+\nu_\mu$		(3.41 ± 0.04) %		864
$K^*(892)^-e^+\nu_e$		(2.15 ± 0.16) %		719
$K^*(892)^-\mu^+\nu_\mu$		(1.89 ± 0.24) %		714
$K^-\pi^0e^+\nu_e$		$(1.6 {}^{+1.3}_{-0.5})$ %		861

$\overline{K}^0 \pi^- e^+ \nu_e$		(1.44 ± 0.04) %		860
$(\overline{K}^0 \pi^-)_{S-wave} e^+ \nu_e$		(7.9 ± 1.7) $\times 10^{-4}$		860
$K^- \pi^+ \pi^- e^+ \nu_e$		(2.8 $^{+1.4}_{-1.1}$) $\times 10^{-4}$		843
$K_1(1270)^- e^+ \nu_e$		(7.6 $^{+4.0}_{-3.1}$) $\times 10^{-4}$		511
$K^- \pi^+ \pi^- \mu^+ \nu_\mu$		< 1.3 $\times 10^{-3}$	CL=90%	821
$(\overline{K}^*(892)\pi)^- \mu^+ \nu_\mu$		< 1.5 $\times 10^{-3}$	CL=90%	692
$\pi^- e^+ \nu_e$		(2.91 ± 0.04) $\times 10^{-3}$		927
$\pi^- \mu^+ \nu_\mu$		(2.67 ± 0.12) $\times 10^{-3}$	S=1.3	924
$\pi^- \pi^0 e^+ \nu_e$		(1.45 ± 0.07) $\times 10^{-3}$		922
$\rho^- e^+ \nu_e$		(1.50 ± 0.12) $\times 10^{-3}$	S=1.9	771
$a(980)^- e^+ \nu_e$, $a^- \rightarrow \eta\pi^-$		(1.33 $^{+0.34}_{-0.30}$) $\times 10^{-4}$		–

Hadronic modes with one $\overline{K}$

$K^- \pi^+$		(3.950± 0.031) %	S=1.2	861
$K^0_S \pi^0$		(1.240± 0.022) %		860
$K^0_L \pi^0$		(10.0 ± 0.7) $\times 10^{-3}$		860
$K^0_S \pi^+ \pi^-$	[nn]	(2.80 ± 0.18) %	S=1.1	842
$K^0_S \rho^0$		(6.3 $^{+0.6}_{-0.8}$) $\times 10^{-3}$		674
$K^0_S \omega$, $\omega \rightarrow \pi^+ \pi^-$		(2.0 ± 0.6) $\times 10^{-4}$		670
$K^0_S (\pi^+ \pi^-)_{S-wave}$		(3.3 ± 0.8) $\times 10^{-3}$		842
$K^0_S f_0(980)$, $f_0 \rightarrow \pi^+ \pi^-$		(1.20 $^{+0.40}_{-0.23}$) $\times 10^{-3}$		549
$K^0_S f_0(1370)$, $f_0 \rightarrow \pi^+ \pi^-$		(2.8 $^{+0.9}_{-1.3}$) $\times 10^{-3}$		†
$K^0_S f_2(1270)$, $f_2 \rightarrow \pi^+ \pi^-$		(9 $^{+10}_{-6}$) $\times 10^{-5}$		262
$K^*(892)^- \pi^+$, $K^{*-} \rightarrow K^0_S \pi^-$		(1.64 $^{+0.14}_{-0.17}$) %		711
$K^*_0(1430)^- \pi^+$, $K^{*-}_0 \rightarrow K^0_S \pi^-$		(2.67 $^{+0.40}_{-0.33}$) $\times 10^{-3}$		378
$K^*_2(1430)^- \pi^+$, $K^{*-}_2 \rightarrow K^0_S \pi^-$		(3.4 $^{+1.9}_{-1.0}$) $\times 10^{-4}$		367
$K^*(1680)^- \pi^+$, $K^{*-} \rightarrow K^0_S \pi^-$		(4.4 ± 3.5) $\times 10^{-4}$		46
$K^*(892)^+ \pi^-$, $K^{*+} \rightarrow K^0_S \pi^+$	[zz]	(1.13 $^{+0.60}_{-0.34}$) $\times 10^{-4}$		711
$K^*_0(1430)^+ \pi^-$, $K^{*+}_0 \rightarrow K^0_S \pi^+$	[zz]	< 1.4 $\times 10^{-5}$	CL=95%	–
$K^*_2(1430)^+ \pi^-$, $K^{*+}_2 \rightarrow K^0_S \pi^+$	[zz]	< 3.4 $\times 10^{-5}$	CL=95%	–
$K^0_S \pi^+ \pi^-$ nonresonant		(2.5 $^{+6.0}_{-1.6}$) $\times 10^{-4}$		842
$K^- \pi^+ \pi^0$	[nn]	(14.4 ± 0.5) %	S=2.0	844
$K^- \rho^+$		(11.3 ± 0.7) %		675
$K^- \rho(1700)^+$, $\rho^+ \rightarrow \pi^+ \pi^0$		(8.2 ± 1.8) $\times 10^{-3}$		†
$K^*(892)^- \pi^+$, $K^*(892)^- \rightarrow K^- \pi^0$		(2.31 $^{+0.40}_{-0.20}$) %		711
$\overline{K}^*(892)^0 \pi^0$, $\overline{K}^*(892)^0 \rightarrow K^- \pi^+$		(1.95 ± 0.24) %		711
$K^*_0(1430)^- \pi^+$, $K^{*-}_0 \rightarrow K^- \pi^0$		(4.8 ± 2.2) $\times 10^{-3}$		378

$\overline{K}_0^*(1430)^0\pi^0$, $\overline{K}_0^{*0} \to K^-\pi^+$		$(5.9 \ {}^{+5.0}_{-1.6}) \times 10^{-3}$		379
$K^*(1680)^-\pi^+$, $K^{*-} \to K^-\pi^0$		$(1.9 \pm 0.7) \times 10^{-3}$		46
$K^-\pi^+\pi^0$ nonresonant		$(1.15 \ {}^{+0.60}_{-0.20})$ %		844
$K_S^0 2\pi^0$		$(9.1 \pm 1.1) \times 10^{-3}$	S=2.2	843
$K_S^0 (2\pi^0)_{S-wave}$		$(2.6 \pm 0.7) \times 10^{-3}$		–
$\overline{K}^*(892)^0\pi^0$, $\overline{K}^{*0} \to K_S^0\pi^0$		$(8.1 \pm 0.7) \times 10^{-3}$		711
$\overline{K}^*(1430)^0\pi^0$, $\overline{K}^{*0} \to K_S^0\pi^0$		$(4 \pm 23) \times 10^{-5}$		–
$\overline{K}^*(1680)^0\pi^0$, $\overline{K}^{*0} \to K_S^0\pi^0$		$(1.0 \pm 0.4) \times 10^{-3}$		–
$K_S^0 f_2(1270)$, $f_2 \to 2\pi^0$		$(2.3 \pm 1.1) \times 10^{-4}$		–
$2K_S^0$, one $K_S^0 \to 2\pi^0$		$(3.2 \pm 1.1) \times 10^{-4}$		–
$K^- 2\pi^+\pi^-$	[nn]	(8.23 ± 0.14) %	S=1.1	813
$K^-\pi^+\rho^0$ total		(6.87 ± 0.31) %		609
$K^-\pi^+\rho^0$ 3-body		$(6.1 \pm 1.6) \times 10^{-3}$		609
$\overline{K}^*(892)^0\rho^0$, $\overline{K}^{*0} \to K^-\pi^+$		(1.01 ± 0.05) %		416
$\overline{K}^*(892)^0\rho^0$ transverse, $\overline{K}^{*0} \to K^-\pi^+$		(1.2 ± 0.4) %		417
$K^- a_1(1260)^+$, $a_1^+ \to \rho^0\pi^+$		(4.33 ± 0.32) %		327
$K_1(1270)^-\pi^+$, $K_1^- \to K^-\pi^+\pi^-$ total		$(3.9 \pm 0.4) \times 10^{-3}$		–
$K_1(1270)^-\pi^+$, $K_1^- \to \overline{K}^*(892)^0\pi^-$, $\overline{K}^{*0} \to K^-\pi^+$		$(6.6 \pm 2.3) \times 10^{-4}$		484
$K^- 2\pi^+\pi^-$ nonresonant		(1.81 ± 0.07) %		813
$K_S^0\pi^+\pi^-\pi^0$	[aaa]	(5.2 ± 0.6) %		813
$K_S^0\eta$, $\eta \to \pi^+\pi^-\pi^0$		$(1.17 \pm 0.03) \times 10^{-3}$		772
$K_S^0\omega$, $\omega \to \pi^+\pi^-\pi^0$		$(9.9 \pm 0.6) \times 10^{-3}$		670
$K^-\pi^+ 2\pi^0$		(8.86 ± 0.23) %		815
$K^- 2\pi^+\pi^-\pi^0$		(4.3 ± 0.4) %		771
$\overline{K}^*(892)^0\pi^+\pi^-\pi^0$, $\overline{K}^{*0} \to K^-\pi^+$		(1.3 ± 0.6) %		643
$K^-\pi^+\omega$, $\omega \to \pi^+\pi^-\pi^0$		(2.8 ± 0.5) %		605
$\overline{K}^*(892)^0\omega$, $\overline{K}^{*0} \to K^-\pi^+$, $\omega \to \pi^+\pi^-\pi^0$		$(6.5 \pm 3.0) \times 10^{-3}$		410
$K_S^0\eta\pi^0$		$(5.7 \pm 1.1) \times 10^{-3}$		721
$K_S^0 a_0(980)$, $a_0 \to \eta\pi^0$		$(6.8 \pm 2.1) \times 10^{-3}$		–
$\overline{K}^*(892)^0\eta$, $\overline{K}^{*0} \to K_S^0\pi^0$		$(1.7 \pm 0.5) \times 10^{-3}$		–
$K_S^0 2\pi^+ 2\pi^-$		$(2.66 \pm 0.30) \times 10^{-3}$		768
$K_S^0\rho^0\pi^+\pi^-$, no $K^*(892)^-$		$(1.1 \pm 0.7) \times 10^{-3}$		–
$K^*(892)^- 2\pi^+\pi^-$, $K^*(892)^- \to K_S^0\pi^-$, no ρ^0		$(5 \pm 7) \times 10^{-4}$		642
$K^*(892)^-\rho^0\pi^+$, $K^*(892)^- \to K_S^0\pi^-$		$(1.6 \pm 0.6) \times 10^{-3}$		230
$K_S^0 2\pi^+ 2\pi^-$ nonresonant		$< 1.2 \times 10^{-3}$	CL=90%	768
$K^- 3\pi^+ 2\pi^-$		$(2.2 \pm 0.6) \times 10^{-4}$		713

Fractions of some of the following modes with resonances have already appeared above as submodes of particular charged-particle modes. These nine modes below are all corrected for unseen decays of the resonances.

$K^0_S \eta$	$(5.09 \pm 0.13) \times 10^{-3}$		772
$K^0_S \omega$	(1.11 ± 0.06) %		670
$K^0_S \eta'(958)$	$(9.49 \pm 0.32) \times 10^{-3}$		565
$\overline{K}^*(892)^0 \pi^+ \pi^- \pi^0$	(1.9 ± 0.9) %		643
$K^- \pi^+ \omega$	(3.1 ± 0.6) %		605
$\overline{K}^*(892)^0 \omega$	(1.1 ± 0.5) %		410
$K^- \pi^+ \eta'(958)$	$(6.43 \pm 0.34) \times 10^{-3}$		479
$K^0_S \eta'(958) \pi^0$	$(2.52 \pm 0.27) \times 10^{-3}$		479
$\overline{K}^*(892)^0 \eta'(958)$	$< 1.0 \times 10^{-3}$	CL=90%	119
Hadronic modes with three K's			
$K^0_S K^+ K^-$	$(4.42 \pm 0.32) \times 10^{-3}$		544
$K^0_S a_0(980)^0$, $a^0_0 \to K^+ K^-$	$(2.9 \pm 0.4) \times 10^{-3}$		–
$K^- a_0(980)^+$, $a^+_0 \to K^+ K^0_S$	$(5.9 \pm 1.8) \times 10^{-4}$		–
$K^+ a_0(980)^-$, $a^-_0 \to K^- K^0_S$	$< 1.1 \times 10^{-4}$	CL=95%	–
$K^0_S f_0(980)$, $f_0 \to K^+ K^-$	$< 9 \times 10^{-5}$	CL=95%	–
$K^0_S \phi$, $\phi \to K^+ K^-$	$(2.03 \pm 0.15) \times 10^{-3}$		520
$K^0_S f_0(1370)$, $f_0 \to K^+ K^-$	$(1.7 \pm 1.1) \times 10^{-4}$		–
$3K^0_S$	$(7.5 \pm 0.7) \times 10^{-4}$	S=1.4	539
$K^+ 2K^- \pi^+$	$(2.25 \pm 0.32) \times 10^{-4}$		434
$K^+ K^- \overline{K}^*(892)^0$, $\overline{K}^{*0} \to K^- \pi^+$	$(4.5 \pm 1.8) \times 10^{-5}$		†
$K^- \pi^+ \phi$, $\phi \to K^+ K^-$	$(4.1 \pm 1.7) \times 10^{-5}$		422
$\phi \overline{K}^*(892)^0$, $\phi \to K^+ K^-$, $\overline{K}^{*0} \to K^- \pi^+$	$(1.08 \pm 0.21) \times 10^{-4}$		†
$K^+ 2K^- \pi^+$ nonresonant	$(3.4 \pm 1.5) \times 10^{-5}$		434
$2K^0_S K^\pm \pi^\mp$	$(5.9 \pm 1.3) \times 10^{-4}$		427
Pionic modes			
$\pi^+ \pi^-$	$(1.455 \pm 0.024) \times 10^{-3}$	S=1.3	922
$2\pi^0$	$(8.26 \pm 0.25) \times 10^{-4}$		923
$\pi^+ \pi^- \pi^0$	(1.49 ± 0.06) %	S=2.1	907
$\rho^+ \pi^-$	(1.01 ± 0.04) %		764
$\rho^0 \pi^0$	$(3.86 \pm 0.23) \times 10^{-3}$		764
$\rho^- \pi^+$	$(5.15 \pm 0.25) \times 10^{-3}$		764
$\rho(1450)^+ \pi^-$, $\rho^+ \to \pi^+ \pi^0$	$(1.6 \pm 2.1) \times 10^{-5}$		–
$\rho(1450)^0 \pi^0$, $\rho^0 \to \pi^+ \pi^-$	$(4.5 \pm 2.0) \times 10^{-5}$		–
$\rho(1450)^- \pi^+$, $\rho^- \to \pi^- \pi^0$	$(2.7 \pm 0.4) \times 10^{-4}$		–
$\rho(1700)^+ \pi^-$, $\rho^+ \to \pi^+ \pi^0$	$(6.1 \pm 1.5) \times 10^{-4}$		–
$\rho(1700)^0 \pi^0$, $\rho^0 \to \pi^+ \pi^-$	$(7.4 \pm 1.8) \times 10^{-4}$		–
$\rho(1700)^- \pi^+$, $\rho^- \to \pi^- \pi^0$	$(4.8 \pm 1.1) \times 10^{-4}$		–
$f_0(980) \pi^0$, $f_0 \to \pi^+ \pi^-$	$(3.7 \pm 0.9) \times 10^{-5}$		–
$f_0(500) \pi^0$, $f_0 \to \pi^+ \pi^-$	$(1.22 \pm 0.22) \times 10^{-4}$		–
$f_0(1370) \pi^0$, $f_0 \to \pi^+ \pi^-$	$(5.5 \pm 2.1) \times 10^{-5}$		–
$f_0(1500) \pi^0$, $f_0 \to \pi^+ \pi^-$	$(5.8 \pm 1.6) \times 10^{-5}$		–
$f_0(1710) \pi^0$, $f_0 \to \pi^+ \pi^-$	$(4.6 \pm 1.6) \times 10^{-5}$		–
$f_2(1270) \pi^0$, $f_2 \to \pi^+ \pi^-$	$(1.97 \pm 0.21) \times 10^{-4}$		–
$\pi^+ \pi^- \pi^0$ nonresonant	$(1.3 \pm 0.4) \times 10^{-4}$		907
$3\pi^0$	$(2.0 \pm 0.5) \times 10^{-4}$		908
$2\pi^+ 2\pi^-$	$(7.56 \pm 0.20) \times 10^{-3}$		880
$a_1(1260)^+ \pi^-$, $a^+_1 \to 2\pi^+ \pi^-$ total	$(4.54 \pm 0.31) \times 10^{-3}$		–

$a_1(1260)^+\pi^-$, $a_1^+ \to \rho^0\pi^+$ S-wave		$(3.14 \pm 0.21) \times 10^{-3}$		–
$a_1(1260)^+\pi^-$, $a_1^+ \to \rho^0\pi^+$ D-wave		$(1.9 \pm 0.5) \times 10^{-4}$		–
$a_1(1260)^+\pi^-$, $a_1^+ \to \sigma\pi^+$		$(6.4 \pm 0.7) \times 10^{-4}$		–
$a_1(1260)^-\pi^+$, $a_1^- \to \rho^0\pi^-$ S-wave		$(2.3 \pm 0.9) \times 10^{-4}$		–
$a_1(1260)^-\pi^+$, $a_1^- \to \sigma\pi^-$		$(6.1 \pm 3.4) \times 10^{-5}$		–
$\pi(1300)^+\pi^-$, $\pi(1300)^+ \to \sigma\pi^+$		$(5.1 \pm 2.7) \times 10^{-4}$		–
$\pi(1300)^-\pi^+$, $\pi(1300)^- \to \sigma\pi^-$		$(2.3 \pm 2.2) \times 10^{-4}$		–
$a_1(1640)^+\pi^-$, $a_1^+ \to \rho^0\pi^+$ D-wave		$(3.2 \pm 1.6) \times 10^{-4}$		–
$a_1(1640)^+\pi^-$, $a_1^+ \to \sigma\pi^+$		$(1.8 \pm 1.4) \times 10^{-4}$		–
$\pi_2(1670)^+\pi^-$, $\pi_2^+ \to f_2(1270)^0\pi^+$, $f_2^0 \to \pi^+\pi^-$		$(2.0 \pm 0.9) \times 10^{-4}$		–
$\pi_2(1670)^+\pi^-$, $\pi_2^+ \to \sigma\pi^+$		$(2.6 \pm 1.0) \times 10^{-4}$		–
$2\rho^0$ total		$(1.85 \pm 0.13) \times 10^{-3}$		518
$2\rho^0$, parallel helicities		$(8.3 \pm 3.2) \times 10^{-5}$		–
$2\rho^0$, perpendicular helicities		$(4.8 \pm 0.6) \times 10^{-4}$		–
$2\rho^0$, longitudinal helicities		$(1.27 \pm 0.10) \times 10^{-3}$		–
$2\rho(770)^0$, S-wave		$(1.8 \pm 1.3) \times 10^{-4}$		–
$2\rho(770)^0$, P-wave		$(5.3 \pm 1.3) \times 10^{-4}$		–
$2\rho(770)^0$, D-wave		$(6.2 \pm 3.0) \times 10^{-4}$		–
Resonant $(\pi^+\pi^-)\pi^+\pi^-$ 3-body total		$(1.51 \pm 0.12) \times 10^{-3}$		–
$\sigma\pi^+\pi^-$		$(6.2 \pm 0.9) \times 10^{-4}$		–
$\sigma\rho(770)^0$		$(5.0 \pm 2.5) \times 10^{-4}$		–
$f_0(980)\pi^+\pi^-$, $f_0 \to \pi^+\pi^-$		$(1.8 \pm 0.5) \times 10^{-4}$		–
$f_2(1270)\pi^+\pi^-$, $f_2 \to \pi^+\pi^-$		$(3.7 \pm 0.6) \times 10^{-4}$		–
$2f_2(1270)$, $f_2 \to \pi^+\pi^-$		$(1.6 \pm 1.8) \times 10^{-4}$		–
$f_0(1370)\sigma$, $f_0 \to \pi^+\pi^-$		$(1.6 \pm 0.5) \times 10^{-3}$		–
$\pi^+\pi^-2\pi^0$		(1.02 ± 0.09) %		882
$\eta\pi^0$	[bbb]	$(6.3 \pm 0.6) \times 10^{-4}$	S=1.1	846
$\omega\pi^0$	[bbb]	$(1.17 \pm 0.35) \times 10^{-4}$		761
$\omega\eta$		$(1.98 \pm 0.18) \times 10^{-3}$	S=1.1	648
$2\pi^+2\pi^-\pi^0$		$(4.2 \pm 0.5) \times 10^{-3}$		844
$\eta\pi^+\pi^-$	[bbb]	$(1.09 \pm 0.16) \times 10^{-3}$		827
$\omega\pi^+\pi^-$	[bbb]	$(1.6 \pm 0.5) \times 10^{-3}$		738
$\eta 2\pi^0$		$(3.8 \pm 1.3) \times 10^{-4}$		829
$3\pi^+3\pi^-$		$(4.3 \pm 1.2) \times 10^{-4}$		795
$\eta'(958)\pi^0$		$(9.2 \pm 1.0) \times 10^{-4}$		678
$\eta'(958)\pi^+\pi^-$		$(4.5 \pm 1.7) \times 10^{-4}$		650
2η		$(2.11 \pm 0.19) \times 10^{-3}$	S=2.2	754
$2\eta\pi^0$		$(7.3 \pm 2.2) \times 10^{-4}$		699
3η		$< 1.3 \times 10^{-4}$	CL=90%	421
$\eta\eta'(958)$		$(1.01 \pm 0.19) \times 10^{-3}$		537

Hadronic modes with a $K\overline{K}$ pair

K^+K^-		$(4.08 \pm 0.06) \times 10^{-3}$	S=1.6	791
$2K_S^0$		$(1.41 \pm 0.05) \times 10^{-4}$	S=1.1	789

$K^0_S K^- \pi^+$	$(3.3 \pm 0.5) \times 10^{-3}$	S=1.1	739
$\overline{K}^*(892)^0 K^0_S$, $\overline{K}^{*0} \to K^- \pi^+$	$(8.2 \pm 1.6) \times 10^{-5}$		608
$K^*(892)^+ K^-$, $K^{*+} \to K^0_S \pi^+$	$(1.89 \pm 0.30) \times 10^{-3}$		–
$\overline{K}^*(1410)^0 K^0_S$, $\overline{K}^{*0} \to K^- \pi^+$	$(1.3 \pm 1.9) \times 10^{-4}$		–
$K^*(1410)^+ K^-$, $K^{*+} \to K^0_S \pi^+$	$(3.2 \pm 1.9) \times 10^{-4}$		–
$(K^- \pi^+)_{S-wave} K^0_S$	$(6.0 \pm 2.9) \times 10^{-4}$		739
$(K^0_S \pi^+)_{S-wave} K^-$	$(3.9 \pm 1.0) \times 10^{-4}$		739
$a_0(980)^- \pi^+$, $a_0^- \to K^0_S K^-$	$(1.3 \pm 1.4) \times 10^{-4}$		–
$a_0(1450)^- \pi^+$, $a_0^- \to K^0_S K^-$	$(2.5 \pm 2.0) \times 10^{-5}$		–
$a_2(1320)^- \pi^+$, $a_2^- \to K^0_S K^-$	$(5 \pm 5) \times 10^{-6}$		–
$\rho(1450)^- \pi^+$, $\rho^- \to K^0_S K^-$	$(4.6 \pm 2.5) \times 10^{-5}$		–
$K^0_S K^+ \pi^-$	$(2.17 \pm 0.34) \times 10^{-3}$	S=1.1	739
$K^*(892)^0 K^0_S$, $K^{*0} \to K^+ \pi^-$	$(1.12 \pm 0.21) \times 10^{-4}$		608
$K^*(892)^- K^+$, $K^{*-} \to K^0_S \pi^-$	$(6.2 \pm 1.0) \times 10^{-4}$		–
$K^*(1410)^0 K^0_S$, $K^{*0} \to K^+ \pi^+$	$(5 \pm 8) \times 10^{-5}$		–
$K^*(1410)^- K^+$, $K^{*-} \to K^0_S \pi^-$	$(2.6 \pm 2.0) \times 10^{-4}$		–
$(K^+ \pi^-)_{S-wave} K^0_S$	$(3.7 \pm 1.9) \times 10^{-4}$		739
$(K^0_S \pi^-)_{S-wave} K^+$	$(1.4 \pm 0.6) \times 10^{-4}$		739
$a_0(980)^+ \pi^-$, $a_0^+ \to K^0_S K^+$	$(6 \pm 4) \times 10^{-4}$		–
$a_0(1450)^+ \pi^-$, $a_0^+ \to K^0_S K^+$	$(3.2 \pm 2.5) \times 10^{-5}$		–
$\rho(1700)^+ \pi^-$, $\rho^+ \to K^0_S K^+$	$(1.1 \pm 0.6) \times 10^{-5}$		–
$K^+ K^- \pi^0$	$(3.42 \pm 0.14) \times 10^{-3}$		743
$K^*(892)^+ K^-$, $K^*(892)^+ \to K^+ \pi^0$	$(1.52 \pm 0.07) \times 10^{-3}$		–
$K^*(892)^- K^+$, $K^*(892)^- \to K^- \pi^0$	$(5.4 \pm 0.4) \times 10^{-4}$		–
$(K^+ \pi^0)_{S-wave} K^-$	$(2.43 \pm 0.18) \times 10^{-3}$		743
$(K^- \pi^0)_{S-wave} K^+$	$(1.3 \pm 0.5) \times 10^{-4}$		743
$f_0(980) \pi^0$, $f_0 \to K^+ K^-$	$(3.6 \pm 0.6) \times 10^{-4}$		–
$\phi \pi^0$, $\phi \to K^+ K^-$	$(6.6 \pm 0.4) \times 10^{-4}$		–
$2K^0_S \pi^0$	$< 5.9 \times 10^{-4}$		740
$K^+ K^- \pi^+ \pi^-$	$(2.47 \pm 0.11) \times 10^{-3}$		677
$\phi(\pi^+ \pi^-)_{S-wave}$, $\phi \to K^+ K^-$	$(10 \pm 5) \times 10^{-5}$		614
$(\phi \rho^0)_{S-wave}$, $\phi \to K^+ K^-$	$(6.9 \pm 0.6) \times 10^{-4}$		250
$(\phi \rho^0)_{P-wave}$, $\phi \to K^+ K^-$	$(4.0 \pm 1.9) \times 10^{-5}$		–
$(\phi \rho^0)_{D-wave}$, $\phi \to K^+ K^-$	$(4.2 \pm 1.4) \times 10^{-5}$		–
$(K^*(892)^0 \overline{K}^*(892)^0)_{S-wave}$, $K^{*0} \to K^\pm \pi^\mp$	$(2.24 \pm 0.13) \times 10^{-4}$		–
$(K^*(892)^0 \overline{K}^*(892)^0)_{P-wave}$, $K^* \to K^\pm \pi^\mp$	$(1.20 \pm 0.08) \times 10^{-4}$		–
$(K^*(892)^0 \overline{K}^*(892)^0)_{D-wave}$, $K^* \to K^\pm \pi^\mp$	$(4.7 \pm 0.4) \times 10^{-5}$		–
$K^*(892)^0 (K^- \pi^+)_{S-wave}$ 3-body, $K^{*0} \to K^+ \pi^-$	$(1.4 \pm 0.6) \times 10^{-4}$		–
$K_1(1270)^+ K^-$, $K_1^+ \to K^{*0} \pi^+$	$(1.4 \pm 0.9) \times 10^{-4}$		–

$K_1(1270)^+ K^-$, $K_1^+ \to K^*(1430)^0 \pi^+$, $K^{*0} \to K^+ \pi^-$		$(1.5 \pm 0.5) \times 10^{-4}$		–
$K_1(1270)^+ K^-$, $K_1^+ \to \rho^0 K^+$		$(2.2 \pm 0.6) \times 10^{-4}$		–
$K_1(1270)^+ K^-$, $K_1^+ \to \omega(782) K^+$, $\omega \to \pi^+ \pi^-$		$(1.5 \pm 1.2) \times 10^{-5}$		–
$K_1(1270)^- K^+$, $K_1^- \to \rho^0 K^-$		$(1.3 \pm 0.4) \times 10^{-4}$		–
$K_1(1400)^+ K^-$, $K_1^+ \to K^*(892)^0 \pi^+$, $K^{*0} \to K^+ \pi^-$		$(4.6 \pm 0.4) \times 10^{-4}$		–
$K^*(1410)^- K^+$, $K^{*-} \to \overline{K}^{*0} \pi^-$		$(7.0 \pm 1.1) \times 10^{-5}$		–
$K_1(1680)^+ K^-$, $K_1^+ \to K^{*0} \pi^+$, $K^{*0} \to K^+ \pi^-$		$(8.9 \pm 3.2) \times 10^{-5}$		–
$K^+ K^- \pi^+ \pi^-$ non-resonant		$(2.7 \pm 0.6) \times 10^{-4}$		–
$2K_S^0 \pi^+ \pi^-$		$(1.22 \pm 0.23) \times 10^{-3}$		673
$K_S^0 K^- 2\pi^+ \pi^-$		$< 1.4 \times 10^{-4}$	CL=90%	595
$K^+ K^- \pi^+ \pi^- \pi^0$		$(3.1 \pm 2.0) \times 10^{-3}$		600

Other $K\overline{K}X$ modes. They include all decay modes of the ϕ, η, and ω.

$\phi\pi^0$		$(1.17 \pm 0.04) \times 10^{-3}$		645
$\phi\eta$		$(1.8 \pm 0.5) \times 10^{-4}$		489
$\phi\omega$		$< 2.1 \times 10^{-3}$	CL=90%	238

Radiative modes

$\rho^0\gamma$		$(1.82 \pm 0.32) \times 10^{-5}$		771
$\omega\gamma$		$< 2.4 \times 10^{-4}$	CL=90%	768
$\phi\gamma$		$(2.81 \pm 0.19) \times 10^{-5}$		654
$\overline{K}^*(892)^0\gamma$		$(4.2 \pm 0.7) \times 10^{-4}$		719

Doubly Cabibbo suppressed (*DC*) modes or
$\Delta C = 2$ forbidden via mixing (*C2M*) modes

$K^+ \ell^- \overline{\nu}_\ell$ via $\overline{D}^0$		$< 2.2 \times 10^{-5}$	CL=90%	–
K^+ or $K^*(892)^+ e^- \overline{\nu}_e$ via $\overline{D}^0$		$< 6 \times 10^{-5}$	CL=90%	–
$K^+ \pi^-$	*DC*	$(1.50 \pm 0.07) \times 10^{-4}$	S=3.0	861
$K^+ \pi^-$ via DCS		$(1.364 \pm 0.026) \times 10^{-4}$		–
$K^+ \pi^-$ via $\overline{D}^0$		$< 1.6 \times 10^{-5}$	CL=95%	861
$K_S^0 \pi^+ \pi^-$ in $D^0 \to \overline{D}^0$		$< 1.8 \times 10^{-4}$	CL=95%	–
$K^*(892)^+ \pi^-$, $K^{*+} \to K_S^0 \pi^+$	*DC*	$(1.13 {}^{+0.60}_{-0.34}) \times 10^{-4}$		711
$K_0^*(1430)^+ \pi^-$, $K_0^{*+} \to K_S^0 \pi^+$	*DC*	$< 1.4 \times 10^{-5}$		–
$K_2^*(1430)^+ \pi^-$, $K_2^{*+} \to K_S^0 \pi^+$	*DC*	$< 3.4 \times 10^{-5}$		–
$K^+ \pi^- \pi^0$	*DC*	$(3.06 \pm 0.15) \times 10^{-4}$		844
$K^+ \pi^- \pi^0$ via $\overline{D}^0$		$(7.6 {}^{+0.5}_{-0.6}) \times 10^{-4}$		–
$K^+ \pi^+ 2\pi^-$ via DCS		$(2.49 \pm 0.07) \times 10^{-4}$		–
$K^+ \pi^+ 2\pi^-$	*DC*	$(2.65 \pm 0.06) \times 10^{-4}$		813
$K^+ \pi^+ 2\pi^-$ via $\overline{D}^0$		$(7.9 \pm 3.0) \times 10^{-6}$		812
μ^- anything via $\overline{D}^0$		$< 4 \times 10^{-4}$	CL=90%	–

$\Delta C = 1$ weak neutral current (*C1*) modes,
Lepton Family number (*LF*) violating modes,
Lepton (*L*) or Baryon (*B*) number violating modes

$\gamma\gamma$	*C1*		< 8.5	$\times 10^{-7}$	CL=90%	932
$e^+ e^-$	*C1*		< 7.9	$\times 10^{-8}$	CL=90%	932
$\mu^+ \mu^-$	*C1*		< 6.2	$\times 10^{-9}$	CL=90%	926
$\pi^0 e^+ e^-$	*C1*		< 4	$\times 10^{-6}$	CL=90%	928
$\pi^0 \mu^+ \mu^-$	*C1*		< 1.8	$\times 10^{-4}$	CL=90%	915
$\eta e^+ e^-$	*C1*		< 3	$\times 10^{-6}$	CL=90%	852
$\eta \mu^+ \mu^-$	*C1*		< 5.3	$\times 10^{-4}$	CL=90%	838
$\pi^+ \pi^- e^+ e^-$	*C1*		< 7	$\times 10^{-6}$	CL=90%	922
$\rho^0 e^+ e^-$	*C1*		< 1.0	$\times 10^{-4}$	CL=90%	771
$\pi^+ \pi^- \mu^+ \mu^-$	*C1*		(9.6 ± 1.2)	$\times 10^{-7}$		894
$\pi^+ \pi^- \mu^+ \mu^-$ (non-res)			< 5.5	$\times 10^{-7}$	CL=90%	–
$\rho^0 \mu^+ \mu^-$	*C1*		< 2.2	$\times 10^{-5}$	CL=90%	754
$\omega e^+ e^-$	*C1*		< 6	$\times 10^{-6}$	CL=90%	768
$\omega \mu^+ \mu^-$	*C1*		< 8.3	$\times 10^{-4}$	CL=90%	751
$K^- K^+ e^+ e^-$	*C1*		< 1.1	$\times 10^{-5}$	CL=90%	791
$\phi e^+ e^-$	*C1*		< 5.2	$\times 10^{-5}$	CL=90%	654
$K^- K^+ \mu^+ \mu^-$	*C1*		(1.54 ± 0.32)	$\times 10^{-7}$		710
$K^- K^+ \mu^+ \mu^-$ (non-res)			< 3.3	$\times 10^{-5}$	CL=90%	–
$\phi \mu^+ \mu^-$	*C1*		< 3.1	$\times 10^{-5}$	CL=90%	631
$\overline{K}^0 e^+ e^-$		[ss]	< 2.4	$\times 10^{-5}$	CL=90%	866
$\overline{K}^0 \mu^+ \mu^-$		[ss]	< 2.6	$\times 10^{-4}$	CL=90%	852
$K^- \pi^+ e^+ e^-$, 675 < m_{ee} < 875 MeV			(4.0 ± 0.5)	$\times 10^{-6}$		–
$K^- \pi^+ e^+ e^-$, 1.005 < m_{ee} < 1.035 GeV			< 5	$\times 10^{-7}$	CL=90%	–
$\overline{K}^*(892)^0 e^+ e^-$		[ss]	< 4.7	$\times 10^{-5}$	CL=90%	719
$K^- \pi^+ \mu^+ \mu^-$	*C1*		< 3.59	$\times 10^{-4}$	CL=90%	829
$K^- \pi^+ \mu^+ \mu^-$, 675 < $m_{\mu\mu}$ < 875 MeV			(4.2 ± 0.4)	$\times 10^{-6}$		–
$\overline{K}^*(892)^0 \mu^+ \mu^-$		[ss]	< 2.4	$\times 10^{-5}$	CL=90%	700
$\pi^+ \pi^- \pi^0 \mu^+ \mu^-$	*C1*		< 8.1	$\times 10^{-4}$	CL=90%	863
$\mu^\pm e^\mp$	*LF*	[bb]	< 1.3	$\times 10^{-8}$	CL=90%	929
$\pi^0 e^\pm \mu^\mp$	*LF*	[bb]	< 8.6	$\times 10^{-5}$	CL=90%	924
$\eta e^\pm \mu^\mp$	*LF*	[bb]	< 1.0	$\times 10^{-4}$	CL=90%	848
$\pi^+ \pi^- e^\pm \mu^\mp$	*LF*	[bb]	< 1.5	$\times 10^{-5}$	CL=90%	911
$\rho^0 e^\pm \mu^\mp$	*LF*	[bb]	< 4.9	$\times 10^{-5}$	CL=90%	767
$\omega e^\pm \mu^\mp$	*LF*	[bb]	< 1.2	$\times 10^{-4}$	CL=90%	764
$K^- K^+ e^\pm \mu^\mp$	*LF*	[bb]	< 1.8	$\times 10^{-4}$	CL=90%	754
$\phi e^\pm \mu^\mp$	*LF*	[bb]	< 3.4	$\times 10^{-5}$	CL=90%	648
$\overline{K}^0 e^\pm \mu^\mp$	*LF*	[bb]	< 1.0	$\times 10^{-4}$	CL=90%	863
$K^- \pi^+ e^\pm \mu^\mp$	*LF*	[bb]	< 5.53	$\times 10^{-4}$	CL=90%	848
$\overline{K}^*(892)^0 e^\pm \mu^\mp$	*LF*	[bb]	< 8.3	$\times 10^{-5}$	CL=90%	714
$2\pi^- 2e^+$ + c.c.	*L*		< 1.12	$\times 10^{-4}$	CL=90%	922
$2\pi^- 2\mu^+$ + c.c.	*L*		< 2.9	$\times 10^{-5}$	CL=90%	894
$K^- \pi^- 2e^+$			< 2.8	$\times 10^{-6}$	CL=90%	861
$K^- \pi^- 2\mu^+$ + c.c.	*L*		< 3.9	$\times 10^{-4}$	CL=90%	829
$2K^- 2e^+$ + c.c.	*L*		< 1.52	$\times 10^{-4}$	CL=90%	791
$2K^- 2\mu^+$ + c.c.	*L*		< 9.4	$\times 10^{-5}$	CL=90%	710
$\pi^- \pi^- e^+ \mu^+$ + c.c.	*L*		< 7.9	$\times 10^{-5}$	CL=90%	911
$K^- \pi^- e^+ \mu^+$ + c.c.	*L*		< 2.18	$\times 10^{-4}$	CL=90%	848
$2K^- e^+ \mu^+$ + c.c.	*L*		< 5.7	$\times 10^{-5}$	CL=90%	754

$p e^-$	L,B	[ccc] $<$ 1.0	$\times 10^{-5}$	CL=90%	696
$\overline{p} e^+$	L,B	[ddd] $<$ 1.1	$\times 10^{-5}$	CL=90%	696

$D^*(2007)^0$

$I(J^P) = \frac{1}{2}(1^-)$
I, J, P need confirmation.

Mass $m = 2006.85 \pm 0.05$ MeV (S = 1.1)
$m_{D^{*0}} - m_{D^0} = 142.014 \pm 0.030$ MeV (S = 1.5)
Full width $\Gamma < 2.1$ MeV, CL = 90%

$\overline{D}^*(2007)^0$ modes are charge conjugates of modes below.

$D^*(2007)^0$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$D^0 \pi^0$	(64.7±0.9) %	43
$D^0 \gamma$	(35.3±0.9) %	137

$D^*(2010)^\pm$

$I(J^P) = \frac{1}{2}(1^-)$
I, J, P need confirmation.

Mass $m = 2010.26 \pm 0.05$ MeV
$m_{D^*(2010)^+} - m_{D^+} = 140.603 \pm 0.015$ MeV
$m_{D^*(2010)^+} - m_{D^0} = 145.4257 \pm 0.0017$ MeV
Full width $\Gamma = 83.4 \pm 1.8$ keV

$D^*(2010)^-$ modes are charge conjugates of the modes below.

$D^*(2010)^\pm$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$D^0 \pi^+$	(67.7±0.5) %	39
$D^+ \pi^0$	(30.7±0.5) %	38
$D^+ \gamma$	(1.6±0.4) %	136

$D_0^*(2300)^0$

$I(J^P) = \frac{1}{2}(0^+)$

was $D_0^*(2400)^0$

Mass $m = 2300 \pm 19$ MeV
Full width $\Gamma = 274 \pm 40$ MeV

$D_1(2420)^0$

$I(J^P) = \frac{1}{2}(1^+)$

Mass $m = 2420.8 \pm 0.5$ MeV (S = 1.3)
$m_{D_1^0} - m_{D^{*+}} = 410.6 \pm 0.5$ MeV (S = 1.3)
Full width $\Gamma = 31.7 \pm 2.5$ MeV (S = 3.5)

$D_2^*(2460)^0$

$I(J^P) = \frac{1}{2}(2^+)$

$J^P = 2^+$ assignment strongly favored.

Mass $m = 2460.7 \pm 0.4$ MeV (S = 3.1)
$m_{D_2^{*0}} - m_{D^+} = 591.0 \pm 0.4$ MeV (S = 2.9)
$m_{D_2^{*0}} - m_{D^{*+}} = 450.4 \pm 0.4$ MeV (S = 2.9)
Full width $\Gamma = 47.5 \pm 1.1$ MeV (S = 1.8)

$D_2^*(2460)^{\pm}$

$I(J^P) = \frac{1}{2}(2^+)$

$J^P = 2^+$ assignment strongly favored.

Mass $m = 2465.4 \pm 1.3$ MeV (S = 3.1)
$m_{D_2^*(2460)^{\pm}} - m_{D_2^*(2460)^0} = 2.4 \pm 1.7$ MeV
Full width $\Gamma = 46.7 \pm 1.2$ MeV

CHARMED, STRANGE MESONS
($C = S = \pm1$)

$D_s^+ = c\overline{s}$, $D_s^- = \overline{c}s$, similarly for D_s^*'s

$D_s^{\pm}$

$I(J^P) = 0(0^-)$

Mass $m = 1968.34 \pm 0.07$ MeV
$m_{D_s^{\pm}} - m_{D^{\pm}} = 98.69 \pm 0.05$ MeV
Mean life $\tau = (504 \pm 4) \times 10^{-15}$ s (S = 1.2)
$c\tau = 151.2$ μm

CP-violating decay-rate asymmetries

$A_{CP}(\mu^{\pm}\nu) = (5 \pm 6)\%$
$A_{CP}(K^{\pm}K_S^0) = (0.09 \pm 0.26)\%$
$A_{CP}(K^{\pm}K_L^0)$ in $D_s^{\pm} \to K^{\pm}K_L^0 = (-1.1 \pm 2.7) \times 10^{-2}$
$A_{CP}(K^+K^-\pi^{\pm}) = (-0.5 \pm 0.9)\%$
$A_{CP}(\phi\pi^{\pm}) = (-0.38 \pm 0.27)\%$
$A_{CP}(K^{\pm}K_S^0\pi^0) = (-2 \pm 6)\%$
$A_{CP}(2K_S^0\pi^{\pm}) = (3 \pm 5)\%$
$A_{CP}(K^+K^-\pi^{\pm}\pi^0) = (0.0 \pm 3.0)\%$
$A_{CP}(K^{\pm}K_S^0\pi^+\pi^-) = (-6 \pm 5)\%$
$A_{CP}(K_S^0K^{\mp}2\pi^{\pm}) = (4.1 \pm 2.8)\%$
$A_{CP}(\pi^+\pi^-\pi^{\pm}) = (-0.7 \pm 3.1)\%$
$A_{CP}(\pi^{\pm}\eta) = (1.1 \pm 3.1)\%$
$A_{CP}(\pi^{\pm}\eta') = (-0.9 \pm 0.5)\%$
$A_{CP}(\eta\pi^{\pm}\pi^0) = (-1 \pm 4)\%$
$A_{CP}(\eta'\pi^{\pm}\pi^0) = (0 \pm 8)\%$
$A_{CP}(K^{\pm}\pi^0) = (-27 \pm 24)\%$
$A_{CP}(\overline{K}^0/K^0\pi^{\pm}) = (0.4 \pm 0.5)\%$
$A_{CP}(K_S^0\pi^{\pm}) = (0.20 \pm 0.18)\%$
$A_{CP}(K^{\pm}\pi^+\pi^-) = (4 \pm 5)\%$
$A_{CP}(K^{\pm}\eta) = (9 \pm 15)\%$
$A_{CP}(K^{\pm}\eta'(958)) = (6 \pm 19)\%$

CP violating asymmetries of P-odd (T-odd) moments

$A_T(K_S^0K^{\pm}\pi^+\pi^-) = (-14 \pm 8) \times 10^{-3}$ [ll]

$D_s^+ \to \phi\ell^+\nu_\ell$ form factors

$r_2 = 0.84 \pm 0.11$ (S = 2.4)
$r_v = 1.80 \pm 0.08$
$\Gamma_L/\Gamma_T = 0.72 \pm 0.18$

$f_+(0)\,|V_{cs}|$ in $D_s^+ \to \eta e^+ \nu_e = 0.446 \pm 0.007$
$f_+(0)\,|V_{cs}|$ in $D_s^+ \to \eta' e^+ \nu_e = 0.48 \pm 0.05$

CP violating asymmetries of P-odd (T-odd) moments

$f_+(0)|V_{cd}|$ in $D_s^+ \to K^0 e^+ \nu_e = 0.162 \pm 0.019$
$r_v \equiv V(0)/A_1(0)$ in $D_s^+ \to K^*(892)^0 e^+ \nu_e = 1.7 \pm 0.4$
$r_2 \equiv A_2(0)/A_1(0)$ in $D_s^+ \to K^*(892)^0 e^+ \nu_e = 0.77 \pm 0.29$
$f_{D_s^+}\,|V_{cs}|$ in $D_s^+ \to \mu^+ \nu_\mu = 246 \pm 5$ MeV

Unless otherwise noted, the branching fractions for modes with a resonance in the final state include all the decay modes of the resonance. D_s^- modes are charge conjugates of the modes below.

D_s^+ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Inclusive modes				
e^+ semileptonic	[eee]	(6.5 ±0.4) %		–
π^+ anything		(119.3 ±1.4) %		–
π^- anything		(43.2 ±0.9) %		–
π^0 anything		(123 ±7) %		–
K^- anything		(18.7 ±0.5) %		–
K^+ anything		(28.9 ±0.7) %		–
K^0_S anything		(19.0 ±1.1) %		–
η anything	[fff]	(29.9 ±2.8) %		–
ω anything		(6.1 ±1.4) %		–
η' anything	[ggg]	(10.3 ±1.4) %	S=1.1	–
$f_0(980)$ anything, $f_0 \to \pi^+\pi^-$		< 1.3 %	CL=90%	–
ϕ anything		(15.7 ±1.0) %		–
K^+K^- anything		(15.8 ±0.7) %		–
$K^0_S K^+$ anything		(5.8 ±0.5) %		–
$K^0_S K^-$ anything		(1.9 ±0.4) %		–
$2K^0_S$ anything		(1.70±0.32) %		–
$2K^+$ anything		< 2.6 $\times 10^{-3}$	CL=90%	–
$2K^-$ anything		< 6 $\times 10^{-4}$	CL=90%	–
Leptonic and semileptonic modes				
$e^+\nu_e$		< 8.3 $\times 10^{-5}$	CL=90%	984
$\mu^+\nu_\mu$		(5.49±0.16) $\times 10^{-3}$		981
$\tau^+\nu_\tau$		(5.48±0.23) %		182
$\gamma e^+\nu_e$		< 1.3 $\times 10^{-4}$	CL=90%	984
$K^+K^-e^+\nu_e$		—		851
$\phi e^+\nu_e$	[hhh]	(2.39±0.16) %	S=1.3	720
$\phi\mu^+\nu_\mu$		(1.9 ±0.5) %		715
$\eta e^+\nu_e + \eta'(958) e^+\nu_e$	[hhh]	(3.03±0.24) %		–
$\eta e^+\nu_e$	[hhh]	(2.32±0.08) %		908
$\eta'(958) e^+\nu_e$	[hhh]	(8.0 ±0.7) $\times 10^{-3}$		751
$\eta\mu^+\nu_\mu$		(2.4 ±0.5) %		905
$\eta'(958)\mu^+\nu_\mu$		(1.1 ±0.5) %		747
$\omega e^+\nu_e$	[iii]	< 2.0 $\times 10^{-3}$	CL=90%	829
$K^0 e^+\nu_e$		(3.4 ±0.4) $\times 10^{-3}$		921
$K^*(892)^0 e^+\nu_e$	[hhh]	(2.15±0.28) $\times 10^{-3}$	S=1.1	782
Hadronic modes with a $K\overline{K}$ pair				
$K^+K^0_S$		(1.46±0.04) %	S=1.1	850
$K^+K^0_L$		(1.49±0.06) %		850

$K^+\overline{K}^0$		(2.95±0.14) %		850
$K^+K^-\pi^+$	[nn]	(5.39±0.15) %	S=1.2	805
$\phi\pi^+$	[hhh,jjj]	(4.5 ±0.4) %		712
$\phi\pi^+$, $\phi\to K^+K^-$	[jjj]	(2.24±0.08) %		712
$K^+\overline{K}^*(892)^0$, $\overline{K}^{*0}\to K^-\pi^+$		(2.58±0.08) %		416
$f_0(980)\pi^+$, $f_0\to K^+K^-$		(1.14±0.31) %		732
$f_0(1370)\pi^+$, $f_0\to K^+K^-$		(7 ±5) × 10^{-4}		–
$f_0(1710)\pi^+$, $f_0\to K^+K^-$		(6.6 ±2.8) × 10^{-4}		198
$K^+\overline{K}^*_0(1430)^0$, $\overline{K}^*_0\to K^-\pi^+$		(1.8 ±0.4) × 10^{-3}		218
$K^+K^0_S\pi^0$		(1.52±0.22) %		805
$2K^0_S\pi^+$		(7.7 ±0.6) × 10^{-3}		802
$K^0\overline{K}^0\pi^+$		—		802
$K^*(892)^+\overline{K}^0$	[hhh]	(5.4 ±1.2) %		683
$K^+K^-\pi^+\pi^0$		(6.2 ±0.6) %	S=1.1	748
$\phi\rho^+$	[hhh]	(8.4 $^{+1.9}_{-2.3}$) %		401
$K^0_S K^-2\pi^+$		(1.65±0.10) %		744
$K^*(892)^+\overline{K}^*(892)^0$	[hhh]	(7.2 ±2.6) %		417
$K^+K^0_S\pi^+\pi^-$		(9.9 ±0.8) × 10^{-3}		744
$K^+K^-2\pi^+\pi^-$		(8.6 ±1.5) × 10^{-3}		673
$\phi 2\pi^+\pi^-$	[hhh]	(1.21±0.16) %		640
$\phi\rho^0\pi^+$, $\phi\to K^+K^-$		(6.5 ±1.3) × 10^{-3}		181
$\phi a_1(1260)^+$, $\phi\to K^+K^-$, $a_1^+\to\rho^0\pi^+$		(7.4 ±1.2) × 10^{-3}		†
$\phi 2\pi^+\pi^-$ non-ρ, $\phi\to K^+K^-$		(1.8 ±0.7) × 10^{-3}		–
$K^+K^-\rho^0\pi^+$ non-ϕ		< 2.6 × 10^{-4}	CL=90%	249
$K^+K^-2\pi^+\pi^-$ nonresonant		(9 ±7) × 10^{-4}		673
$2K^0_S 2\pi^+\pi^-$		(8.4 ±3.5) × 10^{-4}		669

Hadronic modes without *K*'s

$\pi^+\pi^0$		< 3.4 × 10^{-4}	CL=90%	975
$2\pi^+\pi^-$		(1.08±0.04) %	S=1.1	959
$\rho^0\pi^+$		(1.9 ±1.2) × 10^{-4}		825
$\pi^+(\pi^+\pi^-)_{S-\text{wave}}$	[kkk]	(9.0 ±0.4) × 10^{-3}		959
$f_2(1270)\pi^+$, $f_2\to\pi^+\pi^-$		(1.09±0.20) × 10^{-3}		559
$\rho(1450)^0\pi^+$, $\rho^0\to\pi^+\pi^-$		(3.0 ±1.9) × 10^{-4}		421
$\pi^+2\pi^0$		(6.5 ±1.3) × 10^{-3}		961
$2\pi^+\pi^-\pi^0$		—		935
$\eta\pi^+$	[hhh]	(1.68±0.10) %	S=1.2	902
$\omega\pi^+$	[hhh]	(1.92±0.30) × 10^{-3}		822
$3\pi^+2\pi^-$		(7.9 ±0.8) × 10^{-3}		899
$2\pi^+\pi^-2\pi^0$		—		902
$\eta\rho^+$	[hhh]	(8.9 ±0.8) %		724
$\eta\pi^+\pi^0$		(9.5 ±0.5) %		885
$\eta(\pi^+\pi^0)_{P-wave}$		(5.1 ±3.1) × 10^{-3}		885
$a_0(980)^{+0}\pi^{0+}$, $a_0(980)^{+0}\to\eta\pi^{+0}$		(2.2 ±0.4) %		–
$\omega\pi^+\pi^0$	[hhh]	(2.8 ±0.7) %		802
$3\pi^+2\pi^-\pi^0$		(4.9 ±3.2) %		856
$\omega 2\pi^+\pi^-$	[hhh]	(1.6 ±0.5) %		766
$\eta'(958)\pi^+$	[ggg,hhh]	(3.94±0.25) %		743
$3\pi^+2\pi^-2\pi^0$		—		803
$\omega\eta\pi^+$	[hhh]	< 2.13 %	CL=90%	654

$\eta'(958)\rho^+$	[ggg,hhh]	(5.8 ±1.5) %			465
$\eta'(958)\pi^+\pi^0$		(5.6 ±0.8) %			720
$\eta'(958)\pi^+\pi^0$ nonresonant		< 5.1 %		CL=90%	720
Modes with one or three K's					
$K^+\pi^0$		(6.1 ±2.1) × 10^{-4}			917
$K^0_S\pi^+$		(1.19±0.05) × 10^{-3}			916
$K^+\eta$	[hhh]	(1.72±0.34) × 10^{-3}			835
$K^+\omega$	[hhh]	(8.7 ±2.5) × 10^{-4}			741
$K^+\eta'(958)$	[hhh]	(1.7 ±0.5) × 10^{-3}			646
$K^+\pi^+\pi^-$		(6.5 ±0.4) × 10^{-3}			900
$K^+\rho^0$		(2.5 ±0.4) × 10^{-3}			745
$K^+\rho(1450)^0$, $\rho^0 \to \pi^+\pi^-$		(6.9 ±2.4) × 10^{-4}			–
$K^*(892)^0\pi^+$, $K^{*0} \to K^+\pi^-$		(1.41±0.24) × 10^{-3}			775
$K^*(1410)^0\pi^+$, $K^{*0} \to K^+\pi^-$		(1.23±0.28) × 10^{-3}			–
$K^*(1430)^0\pi^+$, $K^{*0} \to K^+\pi^-$		(5.0 ±3.5) × 10^{-4}			–
$K^+\pi^+\pi^-$ nonresonant		(1.03±0.34) × 10^{-3}			900
$K^0\pi^+\pi^0$		(1.00±0.18) %			899
$K^0_S 2\pi^+\pi^-$		(3.0 ±1.1) × 10^{-3}			870
$K^+\omega\pi^0$	[hhh]	< 8.2 × 10^{-3}		CL=90%	684
$K^+\omega\pi^+\pi^-$	[hhh]	< 5.4 × 10^{-3}		CL=90%	603
$K^+\omega\eta$	[hhh]	< 7.9 × 10^{-3}		CL=90%	366
$2K^+K^-$		(2.16±0.20) × 10^{-4}			628
ϕK^+, $\phi \to K^+K^-$		(8.8 ±2.0) × 10^{-5}			–
Doubly Cabibbo-suppressed modes					
$2K^+\pi^-$		(1.28±0.04) × 10^{-4}			805
$K^+K^*(892)^0$, $K^{*0} \to K^+\pi^-$		(6.0 ±3.4) × 10^{-5}			–
Baryon-antibaryon mode					
$p\overline{n}$		(1.22±0.11) × 10^{-3}			295
$p\overline{p}e^+\nu_e$		< 2.0 × 10^{-4}		CL=90%	296
$\Delta C = 1$ weak neutral current (C1) modes, Lepton family number (LF), or Lepton number (L) violating modes					
$\pi^+e^+e^-$	[ss]	< 1.3 × 10^{-5}		CL=90%	979
$\pi^+\phi$, $\phi \to e^+e^-$	[rr]	(6 $^{+8}_{-4}$) × 10^{-6}			–
$\pi^+\mu^+\mu^-$	[ss]	< 4.1 × 10^{-7}		CL=90%	968
$K^+e^+e^-$	C1	< 3.7 × 10^{-6}		CL=90%	922
$K^+\mu^+\mu^-$	C1	< 2.1 × 10^{-5}		CL=90%	909
$K^*(892)^+\mu^+\mu^-$	C1	< 1.4 × 10^{-3}		CL=90%	765
$\pi^+e^+\mu^-$	LF	< 1.2 × 10^{-5}		CL=90%	976
$\pi^+e^-\mu^+$	LF	< 2.0 × 10^{-5}		CL=90%	976
$K^+e^+\mu^-$	LF	< 1.4 × 10^{-5}		CL=90%	919
$K^+e^-\mu^+$	LF	< 9.7 × 10^{-6}		CL=90%	919
π^-2e^+	L	< 4.1 × 10^{-6}		CL=90%	979
$\pi^-2\mu^+$	L	< 1.2 × 10^{-7}		CL=90%	968
$\pi^-e^+\mu^+$	L	< 8.4 × 10^{-6}		CL=90%	976
K^-2e^+	L	< 5.2 × 10^{-6}		CL=90%	922
$K^-2\mu^+$	L	< 1.3 × 10^{-5}		CL=90%	909
$K^-e^+\mu^+$	L	< 6.1 × 10^{-6}		CL=90%	919
$K^*(892)^-2\mu^+$	L	< 1.4 × 10^{-3}		CL=90%	765

$D_s^{*\pm}$

$I(J^P) = 0(?^?)$

J^P is natural, width and decay modes consistent with 1^-.

Mass $m = 2112.2 \pm 0.4$ MeV
$m_{D_s^{*\pm}} - m_{D_s^\pm} = 143.8 \pm 0.4$ MeV
Full width Γ < 1.9 MeV, CL = 90%

D_s^{*-} modes are charge conjugates of the modes below.

D_s^{*+} DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$D_s^+\gamma$	(93.5 ± 0.7) %	139
$D_s^+\pi^0$	(5.8 ± 0.7) %	48
$D_s^+e^+e^-$	$(6.7\pm1.6)\times10^{-3}$	139

$D_{s0}^*(2317)^\pm$

$I(J^P) = 0(0^+)$
J, P need confirmation.

J^P is natural, low mass consistent with 0^+.

Mass $m = 2317.8 \pm 0.5$ MeV
$m_{D_{s0}^*(2317)^\pm} - m_{D_s^\pm} = 349.4 \pm 0.5$ MeV
Full width Γ < 3.8 MeV, CL = 95%

$D_{s0}^*(2317)^-$ modes are charge conjugates of modes below.

$D_{s0}^*(2317)^\pm$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$D_s^+\pi^0$	$(100^{+\ 0}_{-20})$ %		298
$D_s^+\gamma$	< 5 %	90%	323
$D_s^*(2112)^+\gamma$	< 6 %	90%	–
$D_s^+\gamma\gamma$	< 18 %	95%	323
$D_s^*(2112)^+\pi^0$	< 11 %	90%	–
$D_s^+\pi^+\pi^-$	$< 4 \times 10^{-3}$	90%	194

See Particle Listings for 1 decay modes that have been seen / not seen.

$D_{s1}(2460)^\pm$

$I(J^P) = 0(1^+)$

Mass $m = 2459.5 \pm 0.6$ MeV (S = 1.1)
$m_{D_{s1}(2460)^\pm} - m_{D_s^{*\pm}} = 347.3 \pm 0.7$ MeV (S = 1.2)
$m_{D_{s1}(2460)^\pm} - m_{D_s^\pm} = 491.2 \pm 0.6$ MeV (S = 1.1)
Full width Γ < 3.5 MeV, CL = 95%

$D_{s1}(2460)^-$ modes are charge conjugates of the modes below.

$D_{s1}(2460)^+$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$D_s^{*+}\pi^0$	(48 ± 11) %		297
$D_s^+\gamma$	(18 ± 4) %		442
$D_s^+\pi^+\pi^-$	(4.3 ± 1.3) %	S=1.1	363
$D_s^{*+}\gamma$	< 8 %	CL=90%	323
$D_{s0}^*(2317)^+\gamma$	$(3.7^{+5.0}_{-2.4})$ %		138

$D_{s1}(2536)^{\pm}$

$I(J^P) = 0(1^+)$
J, P need confirmation.

Mass $m = 2535.11 \pm 0.06$ MeV
Full width $\Gamma = 0.92 \pm 0.05$ MeV

$D_{s1}(2536)^-$ modes are charge conjugates of the modes below.

$D_{s1}(2536)^+$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$D^*(2010)^+ K^0$	0.85 ± 0.12		149
$(D^*(2010)^+ K^0)_{S-wave}$	0.61 ± 0.09		149
$D^+ \pi^- K^+$	0.028 ± 0.005		176
$D^*(2007)^0 K^+$	**DEFINED AS 1**		167
$D^+ K^0$	<0.34	90%	381
$D^0 K^+$	<0.12	90%	391

See Particle Listings for 2 decay modes that have been seen / not seen.

$D^*_{s2}(2573)$

$I(J^P) = 0(2^+)$

J^P is natural, width and decay modes consistent with 2^+.

Mass $m = 2569.1 \pm 0.8$ MeV (S = 2.4)
Full width $\Gamma = 16.9 \pm 0.7$ MeV

$D^*_{s1}(2700)^{\pm}$

$I(J^P) = 0(1^-)$

Mass $m = 2708.3^{+4.0}_{-3.4}$ MeV
Full width $\Gamma = 120 \pm 11$ MeV

BOTTOM MESONS
$(B = \pm 1)$

$B^+ = u\overline{b}$, $B^0 = d\overline{b}$, $\overline{B}^0 = \overline{d}b$, $B^- = \overline{u}b$, similarly for B^*'s

B-particle organization

Many measurements of B decays involve admixtures of B hadrons. Previously we arbitrarily included such admixtures in the $B^{\pm}$ section, but because of their importance we have created two new sections: "$B^{\pm}/B^0$ Admixture" for $\Upsilon(4S)$ results and "$B^{\pm}/B^0/B^0_s/b$-baryon Admixture" for results at higher energies. Most inclusive decay branching fractions and χ_b at high energy are found in the Admixture sections. B^0-$\overline{B}^0$ mixing data are found in the B^0 section, while B^0_s-$\overline{B}^0_s$ mixing data and B-$\overline{B}$ mixing data for a B^0/B^0_s admixture are found in the B^0_s section. CP-violation data are found in the $B^{\pm}$, B^0, and $B^{\pm}$ B^0 Admixture sections. b-baryons are found near the end of the Baryon section.

The organization of the B sections is now as follows, where bullets indicate particle sections and brackets indicate reviews.

- $B^{\pm}$
  mass, mean life, CP violation, branching fractions
- B^0
  mass, mean life, B^0-$\overline{B}^0$ mixing, CP violation, branching fractions
- $B^{\pm}/B^0$ Admixtures
  CP violation, branching fractions
- $B^{\pm}/B^0/B^0_s/b$-baryon Admixtures
  mean life, production fractions, branching fractions
- B^*
  mass
- $B_1(5721)^+$
  mass
- $B_1(5721)^0$
  mass
- $B^*_2(5747)^+$
  mass
- $B^*_2(5747)^0$
  mass
- $B^*_J(5970)^+$
  mass
- $B^*_J(5970)^0$
  mass
- B^0_s
  mass, mean life, B^0_s-$\overline{B}^0_s$ mixing, CP violation, branching fractions
- B^*_s
  mass
- $B_{s1}(5830)^0$
  mass
- $B^*_{s2}(5840)^0$
  mass
- $B^{\pm}_c$
  mass, mean life, branching fractions

At the end of Baryon Listings:

- Λ_b
  mass, mean life, branching fractions
- $\Lambda_b(5912)^0$
  mass, mean life
- $\Lambda_b(5920)^0$
  mass, mean life
- Σ_b
  mass
- Σ_b^*
  mass
- Ξ_b^0, Ξ_b^-
  mass, mean life, branching fractions
- $\Xi'_b(5935)^-$
  mass
- $\Xi_b(5945)^0$
  mass
- $\Xi_b^*(5955)^-$
  mass
- Ω_b^-
  mass, branching fractions
- b-baryon Admixture
  mean life, branching fractions

$B^{\pm}$

$I(J^P) = \frac{1}{2}(0^-)$

I, J, P need confirmation. Quantum numbers shown are quark-model predictions.

Mass $m_{B^{\pm}} = 5279.34 \pm 0.12$ MeV
Mean life $\tau_{B^{\pm}} = (1.638 \pm 0.004) \times 10^{-12}$ s
$c\tau = 491.1\ \mu$m

CP violation

$A_{CP}(B^+ \to J/\psi(1S) K^+) = (1.8 \pm 3.0) \times 10^{-3}$ (S = 1.5)
$A_{CP}(B^+ \to J/\psi(1S) \pi^+) = (1.8 \pm 1.2) \times 10^{-2}$ (S = 1.3)
$A_{CP}(B^+ \to J/\psi \rho^+) = -0.05 \pm 0.05$
$A_{CP}(B^+ \to J/\psi K^*(892)^+) = -0.048 \pm 0.033$
$A_{CP}(B^+ \to \eta_c K^+) = 0.01 \pm 0.07$ (S = 2.2)
$A_{CP}(B^+ \to \psi(2S) \pi^+) = 0.03 \pm 0.06$
$A_{CP}(B^+ \to \psi(2S) K^+) = 0.012 \pm 0.020$ (S = 1.5)
$A_{CP}(B^+ \to \psi(2S) K^*(892)^+) = 0.08 \pm 0.21$
$A_{CP}(B^+ \to \chi_{c1}(1P) \pi^+) = 0.07 \pm 0.18$
$A_{CP}(B^+ \to \chi_{c0} K^+) = -0.20 \pm 0.18$ (S = 1.5)
$A_{CP}(B^+ \to \chi_{c1} K^+) = -0.009 \pm 0.033$
$A_{CP}(B^+ \to \chi_{c1} K^*(892)^+) = 0.5 \pm 0.5$
$A_{CP}(B^+ \to D^0 \ell^+ \nu_\ell) = (-0.14 \pm 0.20) \times 10^{-2}$
$A_{CP}(B^+ \to \overline{D}^0 \pi^+) = -0.007 \pm 0.007$

$A_{CP}(B^+ \to D_{CP(+1)}\pi^+) = -0.0080 \pm 0.0026$
$A_{CP}(B^+ \to D_{CP(-1)}\pi^+) = 0.017 \pm 0.026$
$A_{CP}([K^{\mp}\pi^{\pm}\pi^+\pi^-]_D\pi^+) = 0.02 \pm 0.05$
$A_{CP}(B^+ \to [\pi^+\pi^+\pi^-\pi^-]_D K^+) = 0.10 \pm 0.04$
$A_{CP}(B^+ \to [\pi^+\pi^-\pi^+\pi^-]_D K^*(892)^+) = 0.02 \pm 0.11$
$A_{CP}(B^+ \to \overline{D}^0 K^+) = -0.017 \pm 0.005$
$A_{CP}([K^{\mp}\pi^{\pm}\pi^+\pi^-]_D K^+) = -0.31 \pm 0.11$
$A_{CP}(B^+ \to [\pi^+\pi^+\pi^-\pi^-]_D\pi^+) = (-4 \pm 8) \times 10^{-3}$
$A_{CP}(B^+ \to [K^-\pi^+]_D K^+) = -0.58 \pm 0.21$
$A_{CP}(B^+ \to [K^-\pi^+\pi^0]_D K^+) = 0.07 \pm 0.30$ (S = 1.5)
$A_{CP}(B^+ \to [K^+K^-\pi^0]_D K^+) = 0.30 \pm 0.20$
$A_{CP}(B^+ \to [\pi^+\pi^-\pi^0]_D K^+) = 0.05 \pm 0.09$
$A_{CP}(B^+ \to \overline{D}^0 K^*(892)^+) = -0.007 \pm 0.019$
$A_{CP}(B^+ \to [K^-\pi^+]_{\overline{D}} K^*(892)^+) = -0.75 \pm 0.16$
$A_{CP}(B^+ \to [K^-\pi^+\pi^-\pi^+]_{\overline{D}} K^*(892)^+) = -0.45 \pm 0.25$
$A_{CP}(B^+ \to [K^-\pi^+]_D\pi^+) = 0.00 \pm 0.09$
$A_{CP}(B^+ \to [K^-\pi^+\pi^0]_D\pi^+) = 0.35 \pm 0.16$
$A_{CP}(B^+ \to [K^+K^-\pi^0]_D\pi^+) = -0.03 \pm 0.04$
$A_{CP}(B^+ \to [\pi^+\pi^-\pi^0]_D\pi^+) = -0.016 \pm 0.020$
$A_{CP}(B^+ \to [K^-\pi^+]_{(D\pi)}\pi^+) = -0.09 \pm 0.27$
$A_{CP}(B^+ \to [K^-\pi^+]_{(D\gamma)}\pi^+) = -0.7 \pm 0.6$
$A_{CP}(B^+ \to [K^-\pi^+]_{(D\pi)} K^+) = 0.8 \pm 0.4$
$A_{CP}(B^+ \to [K^-\pi^+]_{(D\gamma)} K^+) = 0.4 \pm 1.0$
$A_{CP}(B^+ \to [\pi^+\pi^-\pi^0]_D K^+) = -0.02 \pm 0.15$
$A_{CP}(B^+ \to [K^0_S K^+\pi^-]_D K^+) = 0.04 \pm 0.09$
$A_{CP}(B^+ \to [K^0_S K^-\pi^+]_D K^+) = 0.23 \pm 0.13$
$A_{CP}(B^+ \to [K^0_S K^-\pi^+]_D\pi^+) = -0.052 \pm 0.034$
$A_{CP}(B^+ \to [K^0_S K^+\pi^-]_D\pi^+) = -0.025 \pm 0.026$
$A_{CP}(B^+ \to [K^*(892)^-K^+]_D K^+) = 0.03 \pm 0.11$
$A_{CP}(B^+ \to [K^*(892)^+K^-]_D K^+) = 0.34 \pm 0.21$
$A_{CP}(B^+ \to [K^*(892)^+K^-]_D\pi^+) = -0.05 \pm 0.05$
$A_{CP}(B^+ \to [K^*(892)^-K^+]_D\pi^+) = -0.012 \pm 0.030$
$\boldsymbol{A_{CP}(B^+ \to D_{CP(+1)}K^+)} = 0.120 \pm 0.014$ (S = 1.4)
$A_{ADS}(B^+ \to DK^+) = -0.40 \pm 0.06$
$A_{ADS}(B^+ \to D\pi^+) = 0.100 \pm 0.032$
$A_{ADS}(B^+ \to [K^-\pi^+]_D K^+\pi^-\pi^+) = -0.33 \pm 0.35$
$A_{ADS}(B^+ \to [K^-\pi^+]_D\pi^+\pi^-\pi^+) = -0.01 \pm 0.09$
$A_{CP}(B^+ \to D_{CP(-1)}K^+) = -0.10 \pm 0.07$
$A_{CP}(B^+ \to [K^+K^-]_D K^+\pi^-\pi^+) = -0.04 \pm 0.06$
$A_{CP}(B^+ \to [\pi^+\pi^-]_D K^+\pi^-\pi^+) = -0.05 \pm 0.10$
$A_{CP}(B^+ \to [K^-\pi^+]_D K^+\pi^-\pi^+) = 0.013 \pm 0.023$
$A_{CP}(B^+ \to [K^+K^-]_D\pi^+\pi^-\pi^+) = -0.019 \pm 0.015$
$A_{CP}(B^+ \to [\pi^+\pi^-]_D\pi^+\pi^-\pi^+) = -0.013 \pm 0.019$
$A_{CP}(B^+ \to [K^-\pi^+]_D\pi^+\pi^-\pi^+) = -0.002 \pm 0.011$
$A_{CP}(B^+ \to \overline{D}^{*0}\pi^+) = 0.0010 \pm 0.0028$
$A_{CP}(B^+ \to (D^*_{CP(+1)})^0\pi^+) = 0.016 \pm 0.010$ (S = 1.2)
$A_{CP}(B^+ \to (D^*_{CP(-1)})^0\pi^+) = -0.09 \pm 0.05$
$A_{CP}(B^+ \to D^{*0}K^+) = -0.001 \pm 0.011$ (S = 1.1)
$A_{CP}(B^+ \to D^{*0}_{CP(+1)}K^+) = -0.11 \pm 0.08$ (S = 2.7)

$A_{CP}(B^+ \to D^*_{CP(-1)} K^+) = 0.07 \pm 0.10$
$A_{CP}(B^+ \to D_{CP(+1)} K^*(892)^+) = 0.08 \pm 0.06$
$A_{CP}(B^+ \to D_{CP(-1)} K^*(892)^+) = -0.23 \pm 0.22$
$A_{CP}(B^+ \to D_s^+ \phi) = 0.0 \pm 0.4$
$A_{CP}(B^+ \to D_s^+ \overline{D}^0) = (-0.4 \pm 0.7)\%$
$A_{CP}(B^+ \to D^{*+} \overline{D}^{*0}) = -0.15 \pm 0.11$
$A_{CP}(B^+ \to D^{*+} \overline{D}^0) = -0.06 \pm 0.13$
$A_{CP}(B^+ \to D^+ \overline{D}^{*0}) = 0.13 \pm 0.18$
$A_{CP}(B^+ \to D^+ \overline{D}^0) = 0.016 \pm 0.025$
$A_{CP}(B^+ \to K_S^0 \pi^+) = -0.017 \pm 0.016$
$A_{CP}(B^+ \to K^+ \pi^0) = 0.037 \pm 0.021$
$A_{CP}(B^+ \to \eta' K^+) = 0.004 \pm 0.011$
$A_{CP}(B^+ \to \eta' K^*(892)^+) = -0.26 \pm 0.27$
$A_{CP}(B^+ \to \eta' K_0^*(1430)^+) = 0.06 \pm 0.20$
$A_{CP}(B^+ \to \eta' K_2^*(1430)^+) = 0.15 \pm 0.13$
$\boldsymbol{A_{CP}(B^+ \to \eta K^+)} = -0.37 \pm 0.08$
$A_{CP}(B^+ \to \eta K^*(892)^+) = 0.02 \pm 0.06$
$A_{CP}(B^+ \to \eta K_0^*(1430)^+) = 0.05 \pm 0.13$
$A_{CP}(B^+ \to \eta K_2^*(1430)^+) = -0.45 \pm 0.30$
$A_{CP}(B^+ \to \omega K^+) = -0.02 \pm 0.04$
$A_{CP}(B^+ \to \omega K^{*+}) = 0.29 \pm 0.35$
$A_{CP}(B^+ \to \omega (K\pi)_0^{*+}) = -0.10 \pm 0.09$
$A_{CP}(B^+ \to \omega K_2^*(1430)^+) = 0.14 \pm 0.15$
$A_{CP}(B^+ \to K^{*0} \pi^+) = -0.04 \pm 0.09$ (S = 2.1)
$A_{CP}(B^+ \to K^*(892)^+ \pi^0) = -0.39 \pm 0.21$ (S = 1.6)
$\boldsymbol{A_{CP}(B^+ \to K^+ \pi^- \pi^+)} = 0.027 \pm 0.008$
$A_{CP}(B^+ \to K^+ K^- K^+ \text{nonresonant}) = 0.06 \pm 0.05$
$A_{CP}(B^+ \to f(980)^0 K^+) = -0.08 \pm 0.09$
$\boldsymbol{A_{CP}(B^+ \to f_2(1270) K^+)} = -0.68^{+0.19}_{-0.17}$
$A_{CP}(B^+ \to f_0(1500) K^+) = 0.28 \pm 0.30$
$A_{CP}(B^+ \to f_2'(1525)^0 K^+) = -0.08^{+0.05}_{-0.04}$
$\boldsymbol{A_{CP}(B^+ \to \rho^0 K^+)} = 0.37 \pm 0.10$
$A_{CP}(B^+ \to K^0 \pi^+ \pi^0) = 0.07 \pm 0.06$
$A_{CP}(B^+ \to K_0^*(1430)^0 \pi^+) = 0.061 \pm 0.032$
$A_{CP}(B^+ \to K_0^*(1430)^+ \pi^0) = 0.26^{+0.18}_{-0.14}$
$A_{CP}(B^+ \to K_2^*(1430)^0 \pi^+) = 0.05^{+0.29}_{-0.24}$
$A_{CP}(B^+ \to K^+ \pi^0 \pi^0) = -0.06 \pm 0.07$
$A_{CP}(B^+ \to K^0 \rho^+) = -0.03 \pm 0.15$
$A_{CP}(B^+ \to K^{*+} \pi^+ \pi^-) = 0.07 \pm 0.08$
$A_{CP}(B^+ \to \rho^0 K^*(892)^+) = 0.31 \pm 0.13$
$A_{CP}(B^+ \to K^*(892)^+ f_0(980)) = -0.15 \pm 0.12$
$A_{CP}(B^+ \to a_1^+ K^0) = 0.12 \pm 0.11$
$A_{CP}(B^+ \to b_1^+ K^0) = -0.03 \pm 0.15$
$A_{CP}(B^+ \to K^*(892)^0 \rho^+) = -0.01 \pm 0.16$
$A_{CP}(B^+ \to b_1^0 K^+) = -0.46 \pm 0.20$
$A_{CP}(B^+ \to K^0 K^+) = 0.04 \pm 0.14$
$A_{CP}(B^+ \to K_S^0 K^+) = -0.21 \pm 0.14$
$A_{CP}(B^+ \to K^+ K_S^0 K_S^0) = 0.025 \pm 0.031$
$\boldsymbol{A_{CP}(B^+ \to K^+ K^- \pi^+)} = -0.122 \pm 0.021$

$A_{CP}(B^+ \to K^+ K^- \pi^+$ nonresonant$) = -0.11 \pm 0.06$
$A_{CP}(B^+ \to K^+ \overline{K}^*(892)^0) = 0.12 \pm 0.10$
$A_{CP}(B^+ \to K^+ \overline{K}{}^*_0(1430)^0) = 0.10 \pm 0.17$
$A_{CP}(B^+ \to \phi\pi^+) = 0.1 \pm 0.5$
$A_{CP}(B^+ \to \pi^+ (K^+ K^-)_{S-wave}) = -0.66 \pm 0.04$
$\boldsymbol{A_{CP}(B^+ \to K^+ K^- K^+)} = -0.033 \pm 0.008$
$A_{CP}(B^+ \to \phi K^+) = 0.024 \pm 0.028$ (S = 2.3)
$A_{CP}(B^+ \to X_0(1550) K^+) = -0.04 \pm 0.07$
$A_{CP}(B^+ \to K^{*+} K^+ K^-) = 0.11 \pm 0.09$
$A_{CP}(B^+ \to \phi K^*(892)^+) = -0.01 \pm 0.08$
$A_{CP}(B^+ \to \phi (K\pi)^{*+}_0) = 0.04 \pm 0.16$
$A_{CP}(B^+ \to \phi K_1(1270)^+) = 0.15 \pm 0.20$
$A_{CP}(B^+ \to \phi K^*_2(1430)^+) = -0.23 \pm 0.20$
$A_{CP}(B^+ \to K^+ \phi\phi) = -0.10 \pm 0.08$
$A_{CP}(B^+ \to K^+ [\phi\phi]_{\eta_c}) = 0.09 \pm 0.10$
$A_{CP}(B^+ \to K^*(892)^+ \gamma) = 0.014 \pm 0.018$
$A_{CP}(B^+ \to X_s \gamma) = 0.028 \pm 0.019$
$A_{CP}(B^+ \to \eta K^+ \gamma) = -0.12 \pm 0.07$
$A_{CP}(B^+ \to \phi K^+ \gamma) = -0.13 \pm 0.11$ (S = 1.1)
$A_{CP}(B^+ \to \rho^+ \gamma) = -0.11 \pm 0.33$
$A_{CP}(B^+ \to \pi^+ \pi^0) = 0.03 \pm 0.04$
$\boldsymbol{A_{CP}(B^+ \to \pi^+ \pi^- \pi^+)} = 0.057 \pm 0.013$
$A_{CP}(B^+ \to \rho^0 \pi^+) = 0.009 \pm 0.019$
$A_{CP}(B^+ \to f_2(1270) \pi^+) = 0.40 \pm 0.06$
$A_{CP}(B^+ \to \rho^0(1450) \pi^+) = -0.11 \pm 0.05$
$A_{CP}(B^+ \to \rho_3(1690) \pi^+) = -0.80 \pm 0.28$
$\boldsymbol{A_{CP}(B^+ \to f_0(1370) \pi^+)} = 0.72 \pm 0.22$
$A_{CP}(B^+ \to \pi^+ \pi^- \pi^+$ nonresonant$) = -0.14^{+0.23}_{-0.16}$
$A_{CP}(B^+ \to \rho^+ \pi^0) = 0.02 \pm 0.11$
$A_{CP}(B^+ \to \rho^+ \rho^0) = -0.05 \pm 0.05$
$A_{CP}(B^+ \to \omega \pi^+) = -0.04 \pm 0.05$
$A_{CP}(B^+ \to \omega \rho^+) = -0.20 \pm 0.09$
$A_{CP}(B^+ \to \eta \pi^+) = -0.14 \pm 0.07$ (S = 1.4)
$A_{CP}(B^+ \to \eta \rho^+) = 0.11 \pm 0.11$
$A_{CP}(B^+ \to \eta' \pi^+) = 0.06 \pm 0.16$
$A_{CP}(B^+ \to \eta' \rho^+) = 0.26 \pm 0.17$
$A_{CP}(B^+ \to b_1^0 \pi^+) = 0.05 \pm 0.16$
$A_{CP}(B^+ \to p \overline{p} \pi^+) = 0.00 \pm 0.04$
$A_{CP}(B^+ \to p \overline{p} K^+) = 0.00 \pm 0.04$ (S = 2.2)
$A_{CP}(B^+ \to p \overline{p} K^*(892)^+) = 0.21 \pm 0.16$ (S = 1.4)
$A_{CP}(B^+ \to p \overline{\Lambda} \gamma) = 0.17 \pm 0.17$
$A_{CP}(B^+ \to p \overline{\Lambda} \pi^0) = 0.01 \pm 0.17$
$A_{CP}(B^+ \to K^+ \ell^+ \ell^-) = -0.02 \pm 0.08$
$A_{CP}(B^+ \to K^+ e^+ e^-) = 0.14 \pm 0.14$
$A_{CP}(B^+ \to K^+ \mu^+ \mu^-) = 0.011 \pm 0.017$
$A_{CP}(B^+ \to \pi^+ \mu^+ \mu^-) = -0.11 \pm 0.12$
$A_{CP}(B^+ \to K^{*+} \ell^+ \ell^-) = -0.09 \pm 0.14$
$A_{CP}(B^+ \to K^* e^+ e^-) = -0.14 \pm 0.23$
$A_{CP}(B^+ \to K^* \mu^+ \mu^-) = -0.12 \pm 0.24$
$\boldsymbol{\gamma} = (71.1^{+4.6}_{-5.3})^\circ$
$\boldsymbol{r_B(B^+ \to D^0 K^+)} = 0.0993 \pm 0.0046$

$\boldsymbol{\delta_B(B^+ \to D^0 K^+)} = (129.6^{+5.0}_{-6.0})^\circ$
$\mathbf{r_B(B^+ \to D^0 K^{*+})} = 0.076 \pm 0.020$
$\boldsymbol{\delta_B(B^+ \to D^0 K^{*+})} = (98^{+18}_{-37})^\circ$
$\mathbf{r_B(B^+ \to D^{*0} K^+)} = 0.140 \pm 0.019$
$\boldsymbol{\delta_B(B^+ \to D^{*0} K^+)} = (319.2^{+7.7}_{-8.7})^\circ$

B^- modes are charge conjugates of the modes below. Modes which do not identify the charge state of the B are listed in the $B^\pm/B^0$ ADMIXTURE section.

The branching fractions listed below assume 50% $B^0\overline{B}^0$ and 50% B^+B^- production at the $\Upsilon(4S)$. We have attempted to bring older measurements up to date by rescaling their assumed $\Upsilon(4S)$ production ratio to 50:50 and their assumed D, D_s, D^*, and ψ branching ratios to current values whenever this would affect our averages and best limits significantly.

Indentation is used to indicate a subchannel of a previous reaction. All resonant subchannels have been corrected for resonance branching fractions to the final state so the sum of the subchannel branching fractions can exceed that of the final state.

For inclusive branching fractions, *e.g.*, $B \to D^\pm X$, the values usually are multiplicities, not branching fractions. They can be greater than one.

B^+ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Semileptonic and leptonic modes				
$\ell^+\nu_\ell X$	[lll]	(10.99 ± 0.28) %		–
$e^+\nu_e X_c$		(10.8 ± 0.4) %		–
$D\ell^+\nu_\ell X$		(9.7 ± 0.7) %		–
$\overline{D}^0\ell^+\nu_\ell$	[lll]	(2.35 ± 0.09) %		2310
$\overline{D}^0\tau^+\nu_\tau$		(7.7 ± 2.5) $\times 10^{-3}$		1911
$\overline{D}^*(2007)^0\ell^+\nu_\ell$	[lll]	(5.66 ± 0.22) %		2258
$\overline{D}^*(2007)^0\tau^+\nu_\tau$		(1.88 ± 0.20) %		1839
$D^-\pi^+\ell^+\nu_\ell$		(4.4 ± 0.4) $\times 10^{-3}$		2306
$\overline{D}^*_0(2420)^0\ell^+\nu_\ell$, $\overline{D}^{*0}_0 \to D^-\pi^+$		(2.5 ± 0.5) $\times 10^{-3}$		–
$\overline{D}^*_2(2460)^0\ell^+\nu_\ell$, $\overline{D}^{*0}_2 \to D^-\pi^+$		(1.53 ± 0.16) $\times 10^{-3}$		2065
$D^{(*)}n\pi\ell^+\nu_\ell(n \geq 1)$		(1.88 ± 0.25) %		–
$D^{*-}\pi^+\ell^+\nu_\ell$		(6.0 ± 0.4) $\times 10^{-3}$		2254
$\overline{D}_1(2420)^0\ell^+\nu_\ell$, $\overline{D}^0_1 \to D^{*-}\pi^+$		(3.03 ± 0.20) $\times 10^{-3}$		2084
$\overline{D}'_1(2430)^0\ell^+\nu_\ell$, $\overline{D}'^0_1 \to D^{*-}\pi^+$		(2.7 ± 0.6) $\times 10^{-3}$		–
$\overline{D}^*_2(2460)^0\ell^+\nu_\ell$, $\overline{D}^{*0}_2 \to D^{*-}\pi^+$		(1.01 ± 0.24) $\times 10^{-3}$	S=2.0	2065
$\overline{D}^0\pi^+\pi^-\ell^+\nu_\ell$		(1.7 ± 0.4) $\times 10^{-3}$		2301
$\overline{D}^{*0}\pi^+\pi^-\ell^+\nu_\ell$		(8 ± 5) $\times 10^{-4}$		2248
$D^{(*)-}_s K^+\ell^+\nu_\ell$		(6.1 ± 1.0) $\times 10^{-4}$		–
$D^-_s K^+\ell^+\nu_\ell$		(3.0 $^{+1.4}_{-1.2}$) $\times 10^{-4}$		2242
$D^{*-}_s K^+\ell^+\nu_\ell$		(2.9 ± 1.9) $\times 10^{-4}$		2185
$\pi^0\ell^+\nu_\ell$		(7.80 ± 0.27) $\times 10^{-5}$		2638
$\eta\ell^+\nu_\ell$		(3.9 ± 0.5) $\times 10^{-5}$		2611
$\eta'\ell^+\nu_\ell$		(2.3 ± 0.8) $\times 10^{-5}$		2553
$\omega\ell^+\nu_\ell$	[lll]	(1.19 ± 0.09) $\times 10^{-4}$		2582

$\rho^0 \ell^+ \nu_\ell$	[lll]	$(1.58 \pm 0.11) \times 10^{-4}$		2583
$p \overline{p} \ell^+ \nu_\ell$		$(5.8 {}^{+2.6}_{-2.3}) \times 10^{-6}$		2467
$p \overline{p} \mu^+ \nu_\mu$		$< 8.5 \times 10^{-6}$	CL=90%	2446
$p \overline{p} e^+ \nu_e$		$(8.2 {}^{+4.0}_{-3.3}) \times 10^{-6}$		2467
$e^+ \nu_e$		$< 9.8 \times 10^{-7}$	CL=90%	2640
$\mu^+ \nu_\mu$		2.90×10^{-07} to 1.07×10^{-06}	CL=90%	2639
$\tau^+ \nu_\tau$		$(1.09 \pm 0.24) \times 10^{-4}$	S=1.2	2341
$\ell^+ \nu_\ell \gamma$		$< 3.0 \times 10^{-6}$	CL=90%	2640
$e^+ \nu_e \gamma$		$< 4.3 \times 10^{-6}$	CL=90%	2640
$\mu^+ \nu_\mu \gamma$		$< 3.4 \times 10^{-6}$	CL=90%	2639
$\mu^+ \mu^- \mu^+ \nu_\mu$		$< 1.6 \times 10^{-8}$	CL=95%	2634
Inclusive modes				
$D^0 X$		(8.6 ± 0.7) %		–
$\overline{D}^0 X$		(79 ± 4) %		–
$D^+ X$		(2.5 ± 0.5) %		–
$D^- X$		(9.9 ± 1.2) %		–
$D_s^+ X$		$(7.9 {}^{+1.4}_{-1.3})$ %		–
$D_s^- X$		$(1.10 {}^{+0.40}_{-0.32})$ %		–
$\Lambda_c^+ X$		$(2.1 {}^{+0.9}_{-0.6})$ %		–
$\overline{\Lambda}_c^- X$		$(2.8 {}^{+1.1}_{-0.9})$ %		–
$\overline{c} X$		(97 ± 4) %		–
$c X$		$(23.4 {}^{+2.2}_{-1.8})$ %		–
$c / \overline{c} X$		(120 ± 6) %		–
D*, *D*, or D_s modes**				
$\overline{D}^0 \pi^+$		$(4.68 \pm 0.13) \times 10^{-3}$		2308
$D_{CP(+1)} \pi^+$	[nnn]	$(2.05 \pm 0.18) \times 10^{-3}$		–
$D_{CP(-1)} \pi^+$	[nnn]	$(2.0 \pm 0.4) \times 10^{-3}$		–
$\overline{D}^0 \rho^+$		(1.34 ± 0.18) %		2237
$\overline{D}^0 K^+$		$(3.63 \pm 0.12) \times 10^{-4}$		2281
$D_{CP(+1)} K^+$	[nnn]	$(1.80 \pm 0.07) \times 10^{-4}$		–
$D_{CP(-1)} K^+$	[nnn]	$(1.96 \pm 0.18) \times 10^{-4}$		–
$D^0 K^+$		$(3.57 \pm 0.35) \times 10^{-6}$		2281
$[K^- \pi^+]_D K^+$	[ooo]	$< 2.8 \times 10^{-7}$	CL=90%	–
$[K^+ \pi^-]_D K^+$	[ooo]	$< 1.5 \times 10^{-5}$	CL=90%	–
$[K^- \pi^+]_D \pi^+$	[ooo]	$(6.3 \pm 1.1) \times 10^{-7}$		–
$[K^+ \pi^-]_D \pi^+$		$(1.78 \pm 0.32) \times 10^{-4}$		–
$[\pi^+ \pi^- \pi^0]_D K^-$		$(4.6 \pm 0.9) \times 10^{-6}$		–
$\overline{D}^0 K^*(892)^+$		$(5.3 \pm 0.4) \times 10^{-4}$		2213
$D_{CP(-1)} K^*(892)^+$	[nnn]	$(2.7 \pm 0.8) \times 10^{-4}$		–
$D_{CP(+1)} K^*(892)^+$	[nnn]	$(6.2 \pm 0.7) \times 10^{-4}$		–
$D^0 K^*(892)^+$		$(3.1 \pm 1.6) \times 10^{-6}$		2213
$\overline{D}^0 K^+ \pi^+ \pi^-$		$(5.2 \pm 2.1) \times 10^{-4}$		2237
$\overline{D}^0 K^+ \overline{K}^0$		$(5.5 \pm 1.6) \times 10^{-4}$		2189
$\overline{D}^0 K^+ \overline{K}^*(892)^0$		$(7.5 \pm 1.7) \times 10^{-4}$		2072
$\overline{D}^0 \pi^+ \pi^+ \pi^-$		$(5.6 \pm 2.1) \times 10^{-3}$	S=3.6	2289
$\overline{D}^0 \pi^+ \pi^+ \pi^-$ nonresonant		$(5 \pm 4) \times 10^{-3}$		2289
$\overline{D}^0 \pi^+ \rho^0$		$(4.2 \pm 3.0) \times 10^{-3}$		2208
$\overline{D}^0 a_1(1260)^+$		$(4 \pm 4) \times 10^{-3}$		2123

$\overline{D}^0 \omega \pi^+$		$(4.1 \pm 0.9) \times 10^{-3}$		2206
$D^*(2010)^- \pi^+ \pi^+$		$(1.35 \pm 0.22) \times 10^{-3}$		2247
$D^*(2010)^- K^+ \pi^+$		$(8.2 \pm 1.4) \times 10^{-5}$		2206
$\overline{D}_1(2420)^0 \pi^+,\ \overline{D}_1^0 \to D^*(2010)^- \pi^+$		$(5.2 \pm 2.2) \times 10^{-4}$		2081
$D^- \pi^+ \pi^+$		$(1.07 \pm 0.05) \times 10^{-3}$		2299
$D^- K^+ \pi^+$		$(7.7 \pm 0.5) \times 10^{-5}$		2260
$D_0^*(2300)^0 K^+,\ D_0^{*0} \to D^- \pi^+$		$(6.1 \pm 2.4) \times 10^{-6}$		–
$D_2^*(2460)^0 K^+,\ D_2^{*0} \to D^- \pi^+$		$(2.32 \pm 0.23) \times 10^{-5}$		–
$D_1^*(2760)^0 K^+,\ D_1^{*0} \to D^- \pi^+$		$(3.6 \pm 1.2) \times 10^{-6}$		–
$D^+ K^0$		$< 2.9 \times 10^{-6}$	CL=90%	2278
$D^+ K^+ \pi^-$		$(5.6 \pm 1.1) \times 10^{-6}$		2260
$D_2^*(2460)^0 K^+,\ D_2^{*0} \to D^+ \pi^-$		$< 6.3 \times 10^{-7}$	CL=90%	–
$D^+ K^{*0}$		$< 4.9 \times 10^{-7}$	CL=90%	2211
$D^+ \overline{K}^{*0}$		$< 1.4 \times 10^{-6}$	CL=90%	2211
$\overline{D}^*(2007)^0 \pi^+$		$(4.90 \pm 0.17) \times 10^{-3}$		2256
$\overline{D}^{*0}_{CP(+1)} \pi^+$	[ppp]	$(2.7 \pm 0.6) \times 10^{-3}$		–
$D^{*0}_{CP(-1)} \pi^+$	[ppp]	$(2.4 \pm 0.9) \times 10^{-3}$		–
$\overline{D}^*(2007)^0 \omega \pi^+$		$(4.5 \pm 1.2) \times 10^{-3}$		2149
$\overline{D}^*(2007)^0 \rho^+$		$(9.8 \pm 1.7) \times 10^{-3}$		2181
$\overline{D}^*(2007)^0 K^+$		$(3.97 {}^{+0.31}_{-0.28}) \times 10^{-4}$		2227
$\overline{D}^{*0}_{CP(+1)} K^+$	[ppp]	$(2.60 \pm 0.33) \times 10^{-4}$		–
$\overline{D}^{*0}_{CP(-1)} K^+$	[ppp]	$(2.19 \pm 0.30) \times 10^{-4}$		–
$D^*(2007)^0 K^+$		$(7.8 \pm 2.2) \times 10^{-6}$		2227
$\overline{D}^*(2007)^0 K^*(892)^+$		$(8.1 \pm 1.4) \times 10^{-4}$		2156
$\overline{D}^*(2007)^0 K^+ \overline{K}^0$		$< 1.06 \times 10^{-3}$	CL=90%	2132
$\overline{D}^*(2007)^0 K^+ \overline{K}^*(892)^0$		$(1.5 \pm 0.4) \times 10^{-3}$		2009
$\overline{D}^*(2007)^0 \pi^+ \pi^+ \pi^-$		(1.03 ± 0.12) %		2236
$\overline{D}^*(2007)^0 a_1(1260)^+$		(1.9 ± 0.5) %		2063
$\overline{D}^*(2007)^0 \pi^- \pi^+ \pi^+ \pi^0$		(1.8 ± 0.4) %		2219
$\overline{D}^{*0}\, 3\pi^+\, 2\pi^-$		$(5.7 \pm 1.2) \times 10^{-3}$		2196
$D^*(2010)^+ \pi^0$		$< 3.6 \times 10^{-6}$		2255
$D^*(2010)^+ K^0$		$< 9.0 \times 10^{-6}$	CL=90%	2225
$D^*(2010)^- \pi^+ \pi^+ \pi^0$		(1.5 ± 0.7) %		2235
$D^*(2010)^- \pi^+ \pi^+ \pi^+ \pi^-$		$(2.6 \pm 0.4) \times 10^{-3}$		2217
$\overline{D}^{**0} \pi^+$	[qqq]	$(5.7 \pm 1.2) \times 10^{-3}$		–
$\overline{D}_1^*(2420)^0 \pi^+$		$(1.5 \pm 0.6) \times 10^{-3}$	S=1.3	2082
$\overline{D}_1(2420)^0 \pi^+ \times$ B$(\overline{D}_1^0 \to \overline{D}^0 \pi^+ \pi^-)$		$(2.5 {}^{+1.6}_{-1.4}) \times 10^{-4}$	S=3.9	2082
$\overline{D}_1(2420)^0 \pi^+ \times$ B$(\overline{D}_1^0 \to \overline{D}^0 \pi^+ \pi^-$ (nonresonant))		$(2.2 \pm 1.0) \times 10^{-4}$		2082
$\overline{D}_2^*(2462)^0 \pi^+ \times$ B$(\overline{D}_2^*(2462)^0 \to D^- \pi^+)$		$(3.56 \pm 0.24) \times 10^{-4}$		–
$\overline{D}_2^*(2462)^0 \pi^+ \times$B$(\overline{D}_2^{*0} \to \overline{D}^0 \pi^- \pi^+)$		$(2.2 \pm 1.0) \times 10^{-4}$		–
$\overline{D}_2^*(2462)^0 \pi^+ \times$B$(\overline{D}_2^{*0} \to \overline{D}^0 \pi^- \pi^+$ (nonresonant))		$< 1.7 \times 10^{-4}$	CL=90%	–

$\overline{D}_2^*(2462)^0 \pi^+ \times B(\overline{D}_2^{*0} \to D^*(2010)^- \pi^+)$	$(2.2 \pm 1.1) \times 10^{-4}$		–
$\overline{D}_0^*(2400)^0 \pi^+ \times B(\overline{D}_0^*(2400)^0 \to D^- \pi^+)$	$(6.4 \pm 1.4) \times 10^{-4}$		2136
$\overline{D}_1(2421)^0 \pi^+ \times B(\overline{D}_1(2421)^0 \to D^{*-} \pi^+)$	$(6.8 \pm 1.5) \times 10^{-4}$		–
$\overline{D}_2^*(2462)^0 \pi^+ \times B(\overline{D}_2^*(2462)^0 \to D^{*-} \pi^+)$	$(1.8 \pm 0.5) \times 10^{-4}$		–
$\overline{D}'_1(2427)^0 \pi^+ \times B(\overline{D}'_1(2427)^0 \to D^{*-} \pi^+)$	$(5.0 \pm 1.2) \times 10^{-4}$		–
$\overline{D}_1(2420)^0 \pi^+ \times B(\overline{D}_1^0 \to \overline{D}^{*0} \pi^+ \pi^-)$	$< 6 \times 10^{-6}$	CL=90%	2082
$\overline{D}_1^*(2420)^0 \rho^+$	$< 1.4 \times 10^{-3}$	CL=90%	1996
$\overline{D}_2^*(2460)^0 \pi^+$	$< 1.3 \times 10^{-3}$	CL=90%	2063
$\overline{D}_2^*(2460)^0 \pi^+ \times B(\overline{D}_2^{*0} \to \overline{D}^{*0} \pi^+ \pi^-)$	$< 2.2 \times 10^{-5}$	CL=90%	2063
$\overline{D}_1^*(2680)^0 \pi^+$, $\overline{D}_1^*(2680)^0 \to D^- \pi^+$	$(8.4 \pm 2.1) \times 10^{-5}$		–
$\overline{D}_3^*(2760)^0 \pi^+$, $\overline{D}_3^*(2760)^0 \pi^+ \to D^- \pi^+$	$(1.00 \pm 0.22) \times 10^{-5}$		–
$\overline{D}_2^*(3000)^0 \pi^+$, $\overline{D}_2^*(3000)^0 \pi^+ \to D^- \pi^+$	$(2.0 \pm 1.4) \times 10^{-6}$		–
$\overline{D}_2^*(2460)^0 \rho^+$	$< 4.7 \times 10^{-3}$	CL=90%	1977
$\overline{D}^0 D_s^+$	$(9.0 \pm 0.9) \times 10^{-3}$		1815
$D_{s0}^*(2317)^+ \overline{D}^0$, $D_{s0}^{*+} \to D_s^+ \pi^0$	$(8.0 {}^{+1.6}_{-1.3}) \times 10^{-4}$		1605
$D_{s0}(2317)^+ \overline{D}^0 \times B(D_{s0}(2317)^+ \to D_s^{*+} \gamma)$	$< 7.6 \times 10^{-4}$	CL=90%	1605
$D_{s0}(2317)^+ \overline{D}^*(2007)^0 \times B(D_{s0}(2317)^+ \to D_s^+ \pi^0)$	$(9 \pm 7) \times 10^{-4}$		1511
$D_{sJ}(2457)^+ \overline{D}^0$	$(3.1 {}^{+1.0}_{-0.9}) \times 10^{-3}$		–
$D_{sJ}(2457)^+ \overline{D}^0 \times B(D_{sJ}(2457)^+ \to D_s^+ \gamma)$	$(4.6 {}^{+1.3}_{-1.1}) \times 10^{-4}$		–
$D_{sJ}(2457)^+ \overline{D}^0 \times B(D_{sJ}(2457)^+ \to D_s^+ \pi^+ \pi^-)$	$< 2.2 \times 10^{-4}$	CL=90%	–
$D_{sJ}(2457)^+ \overline{D}^0 \times B(D_{sJ}(2457)^+ \to D_s^+ \pi^0)$	$< 2.7 \times 10^{-4}$	CL=90%	–
$D_{sJ}(2457)^+ \overline{D}^0 \times B(D_{sJ}(2457)^+ \to D_s^{*+} \gamma)$	$< 9.8 \times 10^{-4}$	CL=90%	–
$D_{sJ}(2457)^+ \overline{D}^*(2007)^0$	(1.20 ± 0.30) %		–
$D_{sJ}(2457)^+ \overline{D}^*(2007)^0 \times B(D_{sJ}(2457)^+ \to D_s^+ \gamma)$	$(1.4 {}^{+0.7}_{-0.6}) \times 10^{-3}$		–
$\overline{D}^0 D_{s1}(2536)^+ \times B(D_{s1}(2536)^+ \to D^*(2007)^0 K^+ + D^*(2010)^+ K^0)$	$(4.0 \pm 1.0) \times 10^{-4}$		1447
$\overline{D}^0 D_{s1}(2536)^+ \times B(D_{s1}(2536)^+ \to D^*(2007)^0 K^+)$	$(2.2 \pm 0.7) \times 10^{-4}$		1447

$\overline{D}^*(2007)^0 D_{s1}(2536)^+ \times$ B$(D_{s1}(2536)^+ \to$ $D^*(2007)^0 K^+)$		$(\ 5.5\ \pm\ 1.6\ ) \times 10^{-4}$			1339
$\overline{D}^0 D_{s1}(2536)^+ \times$ B$(D_{s1}(2536)^+ \to\ D^{*+} K^0)$		$(\ 2.3\ \pm\ 1.1\ ) \times 10^{-4}$			1447
$\overline{D}^0 D_{sJ}(2700)^+ \times$ B$(D_{sJ}(2700)^+ \to\ D^0 K^+)$		$(\ 5.6\ \pm\ 1.8\ ) \times 10^{-4}$		S=1.7	–
$\overline{D}^{*0} D_{s1}(2536)^+,\ D^+_{s1} \to$ $D^{*+} K^0$		$(\ 3.9\ \pm\ 2.6\ ) \times 10^{-4}$			1339
$\overline{D}^0 D_{sJ}(2573)^+,\ D^+_{sJ} \to\ D^0 K^+$		$(\ 8\ \pm 15\ ) \times 10^{-6}$			–
$\overline{D}^{*0} D_{sJ}(2573),\ D^+_{sJ} \to\ D^0 K^+$	$<$	2	$\times 10^{-4}$	CL=90%	1306
$\overline{D}^*(2007)^0 D_{sJ}(2573),\ D^+_{sJ} \to$ $D^0 K^+$	$<$	5	$\times 10^{-4}$	CL=90%	1306
$\overline{D}^0 D_s^{*+}$		$(\ 7.6\ \pm\ 1.6\ ) \times 10^{-3}$			1734
$\overline{D}^*(2007)^0 D_s^+$		$(\ 8.2\ \pm\ 1.7\ ) \times 10^{-3}$			1737
$\overline{D}^*(2007)^0 D_s^{*+}$		$(\ 1.71\ \pm\ 0.24\ )$ %			1651
$D_s^{(*)+} \overline{D}^{**0}$		$(\ 2.7\ \pm\ 1.2\ )$ %			–
$\overline{D}^*(2007)^0 D^*(2010)^+$		$(\ 8.1\ \pm\ 1.7\ ) \times 10^{-4}$			1713
$\overline{D}^0 D^*(2010)^+ +\ \overline{D}^*(2007)^0 D^+$	$<$	1.30	%	CL=90%	1792
$\overline{D}^0 D^*(2010)^+$		$(\ 3.9\ \pm\ 0.5\ ) \times 10^{-4}$			1792
$\overline{D}^0 D^+$		$(\ 3.8\ \pm\ 0.4\ ) \times 10^{-4}$			1866
$\overline{D}^0 D^+ K^0$		$(\ 1.55\ \pm\ 0.21\ ) \times 10^{-3}$			1571
$D^+ \overline{D}^*(2007)^0$		$(\ 6.3\ \pm\ 1.7\ ) \times 10^{-4}$			1791
$\overline{D}^*(2007)^0 D^+ K^0$		$(\ 2.1\ \pm\ 0.5\ ) \times 10^{-3}$			1475
$\overline{D}^0 D^*(2010)^+ K^0$		$(\ 3.8\ \pm\ 0.4\ ) \times 10^{-3}$			1476
$\overline{D}^*(2007)^0 D^*(2010)^+ K^0$		$(\ 9.2\ \pm\ 1.2\ ) \times 10^{-3}$			1362
$\overline{D}^0 D^0 K^+$		$(\ 1.45\ \pm\ 0.33\ ) \times 10^{-3}$		S=2.6	1577
$\overline{D}^*(2007)^0 D^0 K^+$		$(\ 2.26\ \pm\ 0.23\ ) \times 10^{-3}$			1481
$\overline{D}^0 D^*(2007)^0 K^+$		$(\ 6.3\ \pm\ 0.5\ ) \times 10^{-3}$			1481
$\overline{D}^*(2007)^0 D^*(2007)^0 K^+$		$(\ 1.12\ \pm\ 0.13\ )$ %			1368
$D^- D^+ K^+$		$(\ 2.2\ \pm\ 0.7\ ) \times 10^{-4}$			1571
$D^- D^*(2010)^+ K^+$		$(\ 6.3\ \pm\ 1.1\ ) \times 10^{-4}$			1475
$D^*(2010)^- D^+ K^+$		$(\ 6.0\ \pm\ 1.3\ ) \times 10^{-4}$			1475
$D^*(2010)^- D^*(2010)^+ K^+$		$(\ 1.32\ \pm\ 0.18\ ) \times 10^{-3}$			1363
$(\overline{D}+\overline{D}^*)(D+D^*)K$		$(\ 4.05\ \pm\ 0.30\ )$ %			–
$D_s^+ \pi^0$		$(\ 1.6\ \pm\ 0.5\ ) \times 10^{-5}$			2270
$D_s^{*+} \pi^0$	$<$	2.6	$\times 10^{-4}$	CL=90%	2215
$D_s^+ \eta$	$<$	4	$\times 10^{-4}$	CL=90%	2235
$D_s^{*+} \eta$	$<$	6	$\times 10^{-4}$	CL=90%	2178
$D_s^+ \rho^0$	$<$	3.0	$\times 10^{-4}$	CL=90%	2197
$D_s^{*+} \rho^0$	$<$	4	$\times 10^{-4}$	CL=90%	2138
$D_s^+ \omega$	$<$	4	$\times 10^{-4}$	CL=90%	2195
$D_s^{*+} \omega$	$<$	6	$\times 10^{-4}$	CL=90%	2136
$D_s^+ a_1(1260)^0$	$<$	1.8	$\times 10^{-3}$	CL=90%	2079
$D_s^{*+} a_1(1260)^0$	$<$	1.3	$\times 10^{-3}$	CL=90%	2015
$D_s^+ K^+ K^-$		$(\ 7.2\ \pm\ 1.1\ ) \times 10^{-6}$			2149
$D_s^+ \phi$	$<$	4.2	$\times 10^{-7}$	CL=90%	2141
$D_s^{*+} \phi$	$<$	1.2	$\times 10^{-5}$	CL=90%	2079
$D_s^+ \overline{K}^0$	$<$	8	$\times 10^{-4}$	CL=90%	2242
$D_s^{*+} \overline{K}^0$	$<$	9	$\times 10^{-4}$	CL=90%	2185
$D_s^+ \overline{K}^*(892)^0$	$<$	4.4	$\times 10^{-6}$	CL=90%	2172
$D_s^+ K^{*0}$	$<$	3.5	$\times 10^{-6}$	CL=90%	2172

$D_s^{*+} \overline{K}^*(892)^0$	<	3.5			$\times 10^{-4}$	CL=90%	2112
$D_s^- \pi^+ K^+$	(	1.80	$\pm$ 0.22	)	$\times 10^{-4}$		2222
$D_s^{*-} \pi^+ K^+$	(	1.45	$\pm$ 0.24	)	$\times 10^{-4}$		2164
$D_s^- \pi^+ K^*(892)^+$	<	5			$\times 10^{-3}$	CL=90%	2138
$D_s^{*-} \pi^+ K^*(892)^+$	<	7			$\times 10^{-3}$	CL=90%	2076
$D_s^- K^+ K^+$	(	9.7	$\pm$ 2.1	)	$\times 10^{-6}$		2149
$D_s^{*-} K^+ K^+$	<	1.5			$\times 10^{-5}$	CL=90%	2088
Charmonium modes							
$\eta_c K^+$	(	1.06	$\pm$ 0.09	)	$\times 10^{-3}$	S=1.2	1751
$\eta_c K^+$, $\eta_c \to K_S^0 K^\mp \pi^\pm$	(	2.7	$\pm$ 0.6	)	$\times 10^{-5}$		–
$\eta_c K^*(892)^+$	(	1.1	$^{+0.5}_{-0.4}$	)	$\times 10^{-3}$		1646
$\eta_c K^+ \pi^+ \pi^-$	<	3.9			$\times 10^{-4}$	CL=90%	1684
$\eta_c K^+ \omega(782)$	<	5.3			$\times 10^{-4}$	CL=90%	1475
$\eta_c K^+ \eta$	<	2.2			$\times 10^{-4}$	CL=90%	1588
$\eta_c K^+ \pi^0$	<	6.2			$\times 10^{-5}$	CL=90%	1723
$\eta_c(2S) K^+$	(	4.4	$\pm$ 1.0	)	$\times 10^{-4}$		1320
$\eta_c(2S) K^+$, $\eta_c \to p\overline{p}$	(	3.5	$\pm$ 0.8	)	$\times 10^{-8}$		–
$\eta_c(2S) K^+$, $\eta_c \to K_S^0 K^\mp \pi^\pm$	(	3.4	$^{+2.3}_{-1.6}$	)	$\times 10^{-6}$		–
$\eta_c(2S) K^+$, $\eta_c \to p\overline{p}\pi^+\pi^-$	(	1.12	$\pm$ 0.18	)	$\times 10^{-6}$		–
$h_c(1P) K^+$, $h_c \to J/\psi \pi^+ \pi^-$	<	3.4			$\times 10^{-6}$	CL=90%	1401
$X(3730)^0 K^+$, $X^0 \to \eta_c \eta$	<	4.6			$\times 10^{-5}$	CL=90%	–
$X(3730)^0 K^+$, $X^0 \to \eta_c \pi^0$	<	5.7			$\times 10^{-6}$	CL=90%	–
$\chi_{c1}(3872) K^+$	<	2.6			$\times 10^{-4}$	CL=90%	1141
$\chi_{c1}(3872) K^+$, $\chi_{c1} \to p\overline{p}$	<	5			$\times 10^{-9}$	CL=95%	–
$\chi_{c1}(3872) K^+$, $\chi_{c1} \to J/\psi \pi^+ \pi^-$	(	8.6	$\pm$ 0.8	)	$\times 10^{-6}$		1141
$\chi_{c1}(3872) K^+$, $\chi_{c1} \to J/\psi \gamma$	(	2.1	$\pm$ 0.4	)	$\times 10^{-6}$	S=1.1	1141
$\chi_{c1}(3872) K^+$, $\chi_{c1} \to \psi(2S)\gamma$	(	4	$\pm$ 4	)	$\times 10^{-6}$	S=2.5	1141
$\chi_{c1}(3872) K^+$, $\chi_{c1} \to J/\psi(1S)\eta$	<	7.7			$\times 10^{-6}$	CL=90%	1141
$\chi_{c1}(3872) K^+$, $\chi_{c1} \to D^0 \overline{D}^0$	<	6.0			$\times 10^{-5}$	CL=90%	1141
$\chi_{c1}(3872) K^+$, $\chi_{c1} \to D^+ D^-$	<	4.0			$\times 10^{-5}$	CL=90%	1141
$\chi_{c1}(3872) K^+$, $\chi_{c1} \to D^0 \overline{D}^0 \pi^0$	(	1.0	$\pm$ 0.4	)	$\times 10^{-4}$		1141
$\chi_{c1}(3872) K^+$, $\chi_{c1} \to \overline{D}^{*0} D^0$	(	8.5	$\pm$ 2.6	)	$\times 10^{-5}$	S=1.4	1141
$\chi_{c1}(3872)^0 K^+$, $\chi_{c1}^0 \to \eta_c \pi^+ \pi^-$	<	3.0			$\times 10^{-5}$	CL=90%	–
$\chi_{c1}(3872)^0 K^+$, $\chi_{c1}^0 \to \eta_c \omega(782)$	<	6.9			$\times 10^{-5}$	CL=90%	–
$\chi_{c1}(3872) K^+$, $\chi_{c1} \to \chi_{c1}(1P)\pi^+\pi^-$	<	1.5			$\times 10^{-6}$	CL=90%	–
$\chi_{c1}(3872) K^+$, $\chi_{c1}(3872) \to \chi_{c1}(1P)\pi^0$	<	8.1			$\times 10^{-6}$	CL=90%	–
$X(3915) K^+$	<	2.8			$\times 10^{-4}$	CL=90%	1103
$X(3915)^0 K^+$, $X^0 \to \eta_c \eta$	<	4.7			$\times 10^{-5}$	CL=90%	–
$X(3915)^0 K^+$, $X^0 \to \eta_c \pi^0$	<	1.7			$\times 10^{-5}$	CL=90%	–
$X(4014)^0 K^+$, $X^0 \to \eta_c \eta$	<	3.9			$\times 10^{-5}$	CL=90%	–
$X(4014)^0 K^+$, $X^0 \to \eta_c \pi^0$	<	1.2			$\times 10^{-5}$	CL=90%	–
$Z_c(3900)^0 K^+$, $Z_c^0 \to \eta_c \pi^+ \pi^-$	<	4.7			$\times 10^{-5}$	CL=90%	–
$X(4020)^0 K^+$, $X^0 \to \eta_c \pi^+ \pi^-$	<	1.6			$\times 10^{-5}$	CL=90%	–

$\chi_{c1}(3872) K^*(892)^+$, $\chi_{c1} \to J/\psi\gamma$		$< 4.8 \times 10^{-6}$	CL=90%	939
$\chi_{c1}(3872) K^*(892)^+$, $\chi_{c1} \to \psi(2S)\gamma$		$< 2.8 \times 10^{-5}$	CL=90%	939
$\chi_{c1}(3872)^+ K^0$, $\chi_{c1}^+ \to J/\psi(1S)\pi^+\pi^0$	[rrr]	$< 6.1 \times 10^{-6}$	CL=90%	–
$\chi_{c1}(3872) K^0\pi^+$, $\chi_{c1} \to J/\psi(1S)\pi^+\pi^-$		$(1.06 \pm 0.31) \times 10^{-5}$		–
$Z_c(4430)^+ K^0$, $Z_c^+ \to J/\psi\pi^+$		$< 1.5 \times 10^{-5}$	CL=95%	–
$Z_c(4430)^+ K^0$, $Z_c^+ \to \psi(2S)\pi^+$		$< 4.7 \times 10^{-5}$	CL=95%	–
$\psi(4260)^0 K^+$, $\psi^0 \to J/\psi\pi^+\pi^-$		$< 1.56 \times 10^{-5}$	CL=95%	–
$X(3915) K^+$, $X \to J/\psi\gamma$		$< 1.4 \times 10^{-5}$	CL=90%	–
$X(3915) K^+$, $X \to \chi_{c1}(1P)\pi^0$		$< 3.8 \times 10^{-5}$	CL=90%	–
$X(3930)^0 K^+$, $X^0 \to J/\psi\gamma$		$< 2.5 \times 10^{-6}$	CL=90%	–
$J/\psi(1S) K^+$		$(1.006 \pm 0.027) \times 10^{-3}$		1684
$J/\psi(1S) K^0\pi^+$		$(1.14 \pm 0.11) \times 10^{-3}$		1651
$J/\psi(1S) K^+\pi^+\pi^-$		$(8.1 \pm 1.3) \times 10^{-4}$	S=2.5	1612
$J/\psi(1S) K^+K^-K^+$		$(3.37 \pm 0.29) \times 10^{-5}$		1252
$X(3915) K^+$, $X \to p\overline{p}$		$< 7.1 \times 10^{-8}$	CL=95%	–
$J/\psi(1S) K^*(892)^+$		$(1.43 \pm 0.08) \times 10^{-3}$		1571
$J/\psi(1S) K(1270)^+$		$(1.8 \pm 0.5) \times 10^{-3}$		1402
$J/\psi(1S) K(1400)^+$		$< 5 \times 10^{-4}$	CL=90%	1308
$J/\psi(1S)\eta K^+$		$(1.24 \pm 0.14) \times 10^{-4}$		1510
$\chi_{c1-odd}(3872) K^+$, $\chi_{c1-odd} \to J/\psi\eta$		$< 3.8 \times 10^{-6}$	CL=90%	–
$\psi(4160) K^+$, $\psi \to J/\psi\eta$		$< 7.4 \times 10^{-6}$	CL=90%	–
$J/\psi(1S)\eta' K^+$		$< 8.8 \times 10^{-5}$	CL=90%	1273
$J/\psi(1S)\phi K^+$		$(5.0 \pm 0.4) \times 10^{-5}$		1227
$J/\psi(1S) K_1(1650)$, $K_1 \to \phi K^+$		$(6 {}^{+10}_{-6}) \times 10^{-6}$		–
$J/\psi(1S) K^*(1680)^+$, $K^* \to \phi K^+$		$(3.4 {}^{+1.9}_{-2.2}) \times 10^{-6}$		–
$J/\psi(1S) K_2^*(1980)$, $K_2^* \to \phi K^+$		$(1.5 {}^{+0.9}_{-0.5}) \times 10^{-6}$		–
$J/\psi(1S) K(1830)^+$, $K(1830)^+ \to \phi K^+$		$(1.3 {}^{+1.3}_{-1.1}) \times 10^{-6}$		–
$\chi_{c1}(4140) K^+$, $\chi_{c1} \to J/\psi(1S)\phi$		$(10 \pm 4) \times 10^{-6}$		–
$\chi_{c1}(4274) K^+$, $\chi_{c1} \to J/\psi(1S)\phi$		$(3.6 {}^{+2.2}_{-1.8}) \times 10^{-6}$		–
$\chi_{c0}(4500) K^+$, $\chi_c^0 \to J/\psi(1S)\phi$		$(3.3 {}^{+2.1}_{-1.7}) \times 10^{-6}$		–
$\chi_{c0}(4700) K^+$, $\chi_{c0} \to J/\psi(1S)\phi$		$(6 {}^{+5}_{-4}) \times 10^{-6}$		–
$J/\psi(1S)\omega K^+$		$(3.20 {}^{+0.60}_{-0.32}) \times 10^{-4}$		1388
$\chi_{c1}(3872) K^+$, $\chi_{c1} \to J/\psi\omega$		$(6.0 \pm 2.2) \times 10^{-6}$		1141
$X(3915) K^+$, $X \to J/\psi\omega$		$(3.0 {}^{+0.9}_{-0.7}) \times 10^{-5}$		1103
$J/\psi(1S)\pi^+$		$(3.87 \pm 0.11) \times 10^{-5}$		1728
$J/\psi(1S)\pi^+\pi^+\pi^+\pi^-\pi^-$		$(1.16 \pm 0.13) \times 10^{-5}$		1635
$\psi(2S)\pi^+\pi^+\pi^-$		$(1.9 \pm 0.4) \times 10^{-5}$		1304
$J/\psi(1S)\rho^+$		$(4.1 \pm 0.5) \times 10^{-5}$	S=1.4	1611
$J/\psi(1S)\pi^+\pi^0$ nonresonant		$< 7.3 \times 10^{-6}$	CL=90%	1717
$J/\psi(1S) a_1(1260)^+$		$< 1.2 \times 10^{-3}$	CL=90%	1415

$J/\psi(1S)\, p\overline{p}\pi^+$	<	5.0		$\times 10^{-7}$	CL=90%	643
$J/\psi(1S)\, p\overline{\Lambda}$	(	1.46	± 0.12	) $\times 10^{-5}$		567
$J/\psi(1S)\, \overline{\Sigma}^0\, p$	<	1.1		$\times 10^{-5}$	CL=90%	–
$J/\psi(1S)\, D^+$	<	1.2		$\times 10^{-4}$	CL=90%	871
$J/\psi(1S)\, \overline{D}^0\, \pi^+$	<	2.5		$\times 10^{-5}$	CL=90%	665
$\psi(2S)\, \pi^+$	(	2.44	± 0.30	) $\times 10^{-5}$		1347
$\psi(2S)\, K^+$	(	6.19	± 0.22	) $\times 10^{-4}$		1284
$\psi(2S)\, K^*(892)^+$	(	6.7	± 1.4	) $\times 10^{-4}$	S=1.3	1116
$\psi(2S)\, K^+\pi^+\pi^-$	(	4.3	± 0.5	) $\times 10^{-4}$		1179
$\psi(2S)\, \phi(1020)\, K^+$	(	4.0	± 0.7	) $\times 10^{-6}$		417
$\psi(3770)\, K^+$	(	4.9	± 1.3	) $\times 10^{-4}$		1218
$\psi(3770)\, K+, \psi \to D^0\overline{D}^0$	(	1.5	± 0.5	) $\times 10^{-4}$	S=1.4	1218
$\psi(3770)\, K+, \psi \to D^+ D^-$	(	9.4	± 3.5	) $\times 10^{-5}$		1218
$\psi(3770)\, K^+,\ \psi \to p\overline{p}$	<	2		$\times 10^{-7}$	CL=95%	–
$\psi(4040)\, K^+$	<	1.3		$\times 10^{-4}$	CL=90%	1003
$\psi(4160)\, K^+$	(	5.1	± 2.7	) $\times 10^{-4}$		868
$\psi(4160)\, K^+,\ \psi \to \overline{D}^0 D^0$	(	8	± 5	) $\times 10^{-5}$		–
$\chi_{c0}\, \pi^+,\ \chi_{c0} \to \pi^+\pi^-$	<	1		$\times 10^{-7}$	CL=90%	1531
$\chi_{c0}\, K^+$	(	1.50	$^{+0.15}_{-0.13}$	) $\times 10^{-4}$		1478
$\chi_{c0}\, K^*(892)^+$	<	2.1		$\times 10^{-4}$	CL=90%	1341
$\chi_{c1}(1P)\, \pi^+$	(	2.2	± 0.5	) $\times 10^{-5}$		1468
$\chi_{c1}(1P)\, K^+$	(	4.85	± 0.33	) $\times 10^{-4}$	S=1.5	1412
$\chi_{c1}(1P)\, K^*(892)^+$	(	3.0	± 0.6	) $\times 10^{-4}$	S=1.1	1265
$\chi_{c1}(1P)\, K^0\pi^+$	(	5.8	± 0.4	) $\times 10^{-4}$		1370
$\chi_{c1}(1P)\, K^+\pi^0$	(	3.29	± 0.35	) $\times 10^{-4}$		1373
$\chi_{c1}(1P)\, K^+\pi^+\pi^-$	(	3.74	± 0.30	) $\times 10^{-4}$		1319
$\chi_{c1}(2P)\, K^+,\ \chi_{c1}(2P) \to \pi^+\pi^-\chi_{c1}(1P)$	<	1.1		$\times 10^{-5}$	CL=90%	–
$\chi_{c2}\, K^+$	(	1.1	± 0.4	) $\times 10^{-5}$		1379
$\chi_{c2}\, K^+,\ \chi_{c2} \to p\overline{p}\pi^+\pi^-$	<	1.9		$\times 10^{-7}$		–
$\chi_{c2}\, K^*(892)^+$	<	1.2		$\times 10^{-4}$	CL=90%	1228
$\chi_{c2}\, K^0\pi^+$	(	1.16	± 0.25	) $\times 10^{-4}$		1336
$\chi_{c2}\, K^+\pi^0$	<	6.2		$\times 10^{-5}$	CL=90%	1339
$\chi_{c2}\, K^+\pi^+\pi^-$	(	1.34	± 0.19	) $\times 10^{-4}$		1284
$\chi_{c2}(3930)\pi^+,\ \chi_{c2} \to \pi^+\pi^-$	<	1		$\times 10^{-7}$	CL=90%	1437
$h_c(1P)\, K^+$	(	3.7	± 1.2	) $\times 10^{-5}$		1401
$h_c(1P)\, K^+,\ h_c \to p\overline{p}$	<	6.4		$\times 10^{-8}$	CL=95%	–

K or *K** modes

$K^0\pi^+$	(	2.37	± 0.08	) $\times 10^{-5}$		2614
$K^+\pi^0$	(	1.29	± 0.05	) $\times 10^{-5}$		2615
$\eta' K^+$	(	7.04	± 0.25	) $\times 10^{-5}$		2528
$\eta' K^*(892)^+$	(	4.8	$^{+1.8}_{-1.6}$	) $\times 10^{-6}$		2472
$\eta' K_0^*(1430)^+$	(	5.2	± 2.1	) $\times 10^{-6}$		–
$\eta' K_2^*(1430)^+$	(	2.8	± 0.5	) $\times 10^{-5}$		2346
ηK^+	(	2.4	± 0.4	) $\times 10^{-6}$	S=1.7	2588
$\eta K^*(892)^+$	(	1.93	± 0.16	) $\times 10^{-5}$		2534
$\eta K_0^*(1430)^+$	(	1.8	± 0.4	) $\times 10^{-5}$		–
$\eta K_2^*(1430)^+$	(	9.1	± 3.0	) $\times 10^{-6}$		2414
$\eta(1295)\, K^+ \times$ B($\eta(1295) \to \eta\pi\pi$)	(	2.9	$^{+0.8}_{-0.7}$	) $\times 10^{-6}$		2455
$\eta(1405)\, K^+ \times$ B($\eta(1405) \to \eta\pi\pi$)	<	1.3		$\times 10^{-6}$	CL=90%	2425

$\eta(1405) K^+ \times$ B($\eta(1405) \to K^* K$)	$< 1.2 \times 10^{-6}$	CL=90%	2425
$\eta(1475) K^+ \times$ B($\eta(1475) \to K^* K$)	$(1.38 {}^{+0.21}_{-0.18}) \times 10^{-5}$		2407
$f_1(1285) K^+$	$< 2.0 \times 10^{-6}$	CL=90%	2458
$f_1(1420) K^+ \times$ B($f_1(1420) \to \eta\pi\pi$)	$< 2.9 \times 10^{-6}$	CL=90%	2420
$f_1(1420) K^+ \times$ B($f_1(1420) \to K^* K$)	$< 4.1 \times 10^{-6}$	CL=90%	2420
$\phi(1680) K^+ \times$ B($\phi(1680) \to K^* K$)	$< 3.4 \times 10^{-6}$	CL=90%	2344
$f_0(1500) K^+$	$(3.7 \pm 2.2) \times 10^{-6}$		2398
ωK^+	$(6.5 \pm 0.4) \times 10^{-6}$		2558
$\omega K^*(892)^+$	$< 7.4 \times 10^{-6}$	CL=90%	2503
$\omega (K\pi)^{*+}_0$	$(2.8 \pm 0.4) \times 10^{-5}$		–
$\omega K^*_0(1430)^+$	$(2.4 \pm 0.5) \times 10^{-5}$		–
$\omega K^*_2(1430)^+$	$(2.1 \pm 0.4) \times 10^{-5}$		2379
$a_0(980)^+ K^0 \times$B($a_0(980)^+ \to \eta\pi^+$)	$< 3.9 \times 10^{-6}$	CL=90%	–
$a_0(980)^0 K^+ \times$B($a_0(980)^0 \to \eta\pi^0$)	$< 2.5 \times 10^{-6}$	CL=90%	–
$K^*(892)^0 \pi^+$	$(1.01 \pm 0.08) \times 10^{-5}$		2562
$K^*(892)^+ \pi^0$	$(6.8 \pm 0.9) \times 10^{-6}$		2563
$K^+ \pi^- \pi^+$	$(5.10 \pm 0.29) \times 10^{-5}$		2609
$K^+ \pi^- \pi^+$ nonresonant	$(1.63 {}^{+0.21}_{-0.15}) \times 10^{-5}$		2609
$\omega(782) K^+$	$(6 \pm 9) \times 10^{-6}$		2558
$K^+ f_0(980) \times$ B($f_0(980) \to \pi^+\pi^-$)	$(9.4 {}^{+1.0}_{-1.2}) \times 10^{-6}$		2522
$f_2(1270)^0 K^+$	$(1.07 \pm 0.27) \times 10^{-6}$		–
$f_0(1370)^0 K^+ \times$ B($f_0(1370)^0 \to \pi^+\pi^-$)	$< 1.07 \times 10^{-5}$	CL=90%	–
$\rho^0(1450) K^+ \times$ B($\rho^0(1450) \to \pi^+\pi^-$)	$< 1.17 \times 10^{-5}$	CL=90%	–
$f'_2(1525) K^+ \times$ B($f'_2(1525) \to \pi^+\pi^-$)	$< 3.4 \times 10^{-6}$	CL=90%	2394
$K^+ \rho^0$	$(3.7 \pm 0.5) \times 10^{-6}$		2559
$K^*_0(1430)^0 \pi^+$	$(3.9 {}^{+0.6}_{-0.5}) \times 10^{-5}$	S=1.4	2445
$K^*_0(1430)^+ \pi^0$	$(1.19 {}^{+0.20}_{-0.23}) \times 10^{-5}$		–
$K^*_2(1430)^0 \pi^+$	$(5.6 {}^{+2.2}_{-1.5}) \times 10^{-6}$		2445
$K^*(1410)^0 \pi^+$	$< 4.5 \times 10^{-5}$	CL=90%	2448
$K^*(1680)^0 \pi^+$	$< 1.2 \times 10^{-5}$	CL=90%	2358
$K^+ \pi^0 \pi^0$	$(1.62 \pm 0.19) \times 10^{-5}$		2610
$f_0(980) K^+ \times$ B($f_0 \to \pi^0\pi^0$)	$(2.8 \pm 0.8) \times 10^{-6}$		2522
$K^- \pi^+ \pi^+$	$< 4.6 \times 10^{-8}$	CL=90%	2609
$K^- \pi^+ \pi^+$ nonresonant	$< 5.6 \times 10^{-5}$	CL=90%	2609
$K_1(1270)^0 \pi^+$	$< 4.0 \times 10^{-5}$	CL=90%	2489
$K_1(1400)^0 \pi^+$	$< 3.9 \times 10^{-5}$	CL=90%	2451
$K^0 \pi^+ \pi^0$	$< 6.6 \times 10^{-5}$	CL=90%	2609
$K^0 \rho^+$	$(7.3 {}^{+1.0}_{-1.2}) \times 10^{-6}$		2558
$K^*(892)^+ \pi^+ \pi^-$	$(7.5 \pm 1.0) \times 10^{-5}$		2557
$K^*(892)^+ \rho^0$	$(4.6 \pm 1.1) \times 10^{-6}$		2504

$K^*(892)^+ f_0(980)$	$(4.2 \pm 0.7) \times 10^{-6}$		2466
$a_1^+ K^0$	$(3.5 \pm 0.7) \times 10^{-5}$		–
$b_1^+ K^0 \times$ B$(b_1^+ \to \omega\pi^+)$	$(9.6 \pm 1.9) \times 10^{-6}$		–
$K^*(892)^0 \rho^+$	$(9.2 \pm 1.5) \times 10^{-6}$		2504
$K_1(1400)^+ \rho^0$	$< 7.8 \times 10^{-4}$	CL=90%	2388
$K_2^*(1430)^+ \rho^0$	$< 1.5 \times 10^{-3}$	CL=90%	2381
$b_1^0 K^+ \times$ B$(b_1^0 \to \omega\pi^0)$	$(9.1 \pm 2.0) \times 10^{-6}$		–
$b_1^+ K^{*0} \times$ B$(b_1^+ \to \omega\pi^+)$	$< 5.9 \times 10^{-6}$	CL=90%	–
$b_1^0 K^{*+} \times$ B$(b_1^0 \to \omega\pi^0)$	$< 6.7 \times 10^{-6}$	CL=90%	–
$K^+ \overline{K}^0$	$(1.31 \pm 0.17) \times 10^{-6}$	S=1.2	2593
$\overline{K}^0 K^+ \pi^0$	$< 2.4 \times 10^{-5}$	CL=90%	2578
$K^+ K_S^0 K_S^0$	$(1.05 \pm 0.04) \times 10^{-5}$		2521
$f_0(980) K^+,\ f_0 \to K_S^0 K_S^0$	$(1.47 \pm 0.33) \times 10^{-5}$		–
$f_0(1710) K^+,\ f_0 \to K_S^0 K_S^0$	$(4.8 {}^{+4.0}_{-2.6}) \times 10^{-7}$		–
$K^+ K_S^0 K_S^0$ nonresonant	$(2.0 \pm 0.4) \times 10^{-5}$		2521
$K_S^0 K_S^0 \pi^+$	$< 5.1 \times 10^{-7}$	CL=90%	2577
$K^+ K^- \pi^+$	$(5.2 \pm 0.4) \times 10^{-6}$		2578
$K^+ K^- \pi^+$ nonresonant	$(1.68 \pm 0.26) \times 10^{-6}$		2578
$K^+ \overline{K}^*(892)^0$	$(5.9 \pm 0.8) \times 10^{-7}$		2540
$K^+ \overline{K}_0^*(1430)^0$	$(3.8 \pm 1.3) \times 10^{-7}$		2421
$\pi^+ (K^+ K^-)_{S-wave}$	$(8.5 \pm 0.9) \times 10^{-7}$		2578
$K^+ K^+ \pi^-$	$< 1.1 \times 10^{-8}$	CL=90%	2578
$K^+ K^+ \pi^-$ nonresonant	$< 8.79 \times 10^{-5}$	CL=90%	2578
$f_2'(1525) K^+$	$(1.8 \pm 0.5) \times 10^{-6}$	S=1.1	2394
$K^{*+} \pi^+ K^-$	$< 1.18 \times 10^{-5}$	CL=90%	2524
$K^*(892)^+ K^*(892)^0$	$(9.1 \pm 2.9) \times 10^{-7}$		2485
$K^{*+} K^+ \pi^-$	$< 6.1 \times 10^{-6}$	CL=90%	2524
$K^+ K^- K^+$	$(3.40 \pm 0.14) \times 10^{-5}$	S=1.4	2523
$K^+ \phi$	$(8.8 {}^{+0.7}_{-0.6}) \times 10^{-6}$	S=1.1	2516
$f_0(980) K^+ \times$ B$(f_0(980) \to K^+ K^-)$	$(9.4 \pm 3.2) \times 10^{-6}$		2522
$a_2(1320) K^+ \times$ B$(a_2(1320) \to K^+ K^-)$	$< 1.1 \times 10^{-6}$	CL=90%	2449
$X_0(1550) K^+ \times$ B$(X_0(1550) \to K^+ K^-)$	$(4.3 \pm 0.7) \times 10^{-6}$		–
$\phi(1680) K^+ \times$ B$(\phi(1680) \to K^+ K^-)$	$< 8 \times 10^{-7}$	CL=90%	2344
$f_0(1710) K^+ \times$ B$(f_0(1710) \to K^+ K^-)$	$(1.1 \pm 0.6) \times 10^{-6}$		2336
$K^+ K^- K^+$ nonresonant	$(2.38 {}^{+0.28}_{-0.50}) \times 10^{-5}$		2523
$K^*(892)^+ K^+ K^-$	$(3.6 \pm 0.5) \times 10^{-5}$		2466
$K^*(892)^+ \phi$	$(10.0 \pm 2.0) \times 10^{-6}$	S=1.7	2460
$\phi (K\pi)_0^{*+}$	$(8.3 \pm 1.6) \times 10^{-6}$		–
$\phi K_1(1270)^+$	$(6.1 \pm 1.9) \times 10^{-6}$		2380
$\phi K_1(1400)^+$	$< 3.2 \times 10^{-6}$	CL=90%	2339
$\phi K^*(1410)^+$	$< 4.3 \times 10^{-6}$	CL=90%	–
$\phi K_0^*(1430)^+$	$(7.0 \pm 1.6) \times 10^{-6}$		–
$\phi K_2^*(1430)^+$	$(8.4 \pm 2.1) \times 10^{-6}$		2332
$\phi K_2^*(1770)^+$	$< 1.50 \times 10^{-5}$	CL=90%	–
$\phi K_2^*(1820)^+$	$< 1.63 \times 10^{-5}$	CL=90%	–
$a_1^+ K^{*0}$	$< 3.6 \times 10^{-6}$	CL=90%	–

$K^+\phi\phi$	$(5.0 \pm 1.2) \times 10^{-6}$	S=2.3	2306
$\eta'\eta' K^+$	$< 2.5 \times 10^{-5}$	CL=90%	2338
$\omega\phi K^+$	$< 1.9 \times 10^{-6}$	CL=90%	2374
$X(1812) K^+ \times B(X \to \omega\phi)$	$< 3.2 \times 10^{-7}$	CL=90%	–
$K^*(892)^+\gamma$	$(3.92 \pm 0.22) \times 10^{-5}$	S=1.7	2564
$K_1(1270)^+\gamma$	$(4.4 {}^{+0.7}_{-0.6}) \times 10^{-5}$		2491
$\eta K^+\gamma$	$(7.9 \pm 0.9) \times 10^{-6}$		2588
$\eta' K^+\gamma$	$(2.9 {}^{+1.0}_{-0.9}) \times 10^{-6}$		2528
$\phi K^+\gamma$	$(2.7 \pm 0.4) \times 10^{-6}$	S=1.2	2516
$K^+\pi^-\pi^+\gamma$	$(2.58 \pm 0.15) \times 10^{-5}$	S=1.3	2609
$K^*(892)^0\pi^+\gamma$	$(2.33 \pm 0.12) \times 10^{-5}$		2562
$K^+\rho^0\gamma$	$(8.2 \pm 0.9) \times 10^{-6}$		2559
$(K^+\pi^-)_{NR}\pi^+\gamma$	$(9.9 {}^{+1.7}_{-2.0}) \times 10^{-6}$		2609
$K^0\pi^+\pi^0\gamma$	$(4.6 \pm 0.5) \times 10^{-5}$		2609
$K_1(1400)^+\gamma$	$(10 {}^{+5}_{-4}) \times 10^{-6}$		2453
$K^*(1410)^+\gamma$	$(2.7 {}^{+0.8}_{-0.6}) \times 10^{-5}$		–
$K_0^*(1430)^0\pi^+\gamma$	$(1.32 {}^{+0.26}_{-0.32}) \times 10^{-6}$		2445
$K_2^*(1430)^+\gamma$	$(1.4 \pm 0.4) \times 10^{-5}$		2447
$K^*(1680)^+\gamma$	$(6.7 {}^{+1.7}_{-1.4}) \times 10^{-5}$		2360
$K_3^*(1780)^+\gamma$	$< 3.9 \times 10^{-5}$	CL=90%	2341
$K_4^*(2045)^+\gamma$	$< 9.9 \times 10^{-3}$	CL=90%	2242

Light unflavored meson modes

$\rho^+\gamma$	$(9.8 \pm 2.5) \times 10^{-7}$		2583
$\pi^+\pi^0$	$(5.5 \pm 0.4) \times 10^{-6}$	S=1.2	2636
$\pi^+\pi^+\pi^-$	$(1.52 \pm 0.14) \times 10^{-5}$		2630
$\rho^0\pi^+$	$(8.3 \pm 1.2) \times 10^{-6}$		2581
$\pi^+ f_0(980),\ f_0 \to \pi^+\pi^-$	$< 1.5 \times 10^{-6}$	CL=90%	2545
$\pi^+ f_2(1270)$	$(2.2 {}^{+0.7}_{-0.4}) \times 10^{-6}$		2484
$\rho(1450)^0\pi^+,\ \rho^0 \to \pi^+\pi^-$	$(1.4 {}^{+0.6}_{-0.9}) \times 10^{-6}$		2434
$\rho(1450)^0\pi^+,\ \rho^0 \to K^+K^-$	$(1.60 \pm 0.14) \times 10^{-6}$		–
$f_0(1370)\pi^+,\ f_0 \to \pi^+\pi^-$	$< 4.0 \times 10^{-6}$	CL=90%	2460
$f_0(500)\pi^+,\ f_0 \to \pi^+\pi^-$	$< 4.1 \times 10^{-6}$	CL=90%	–
$\pi^+\pi^-\pi^+$ nonresonant	$(5.3 {}^{+1.5}_{-1.1}) \times 10^{-6}$		2630
$\pi^+\pi^0\pi^0$	$< 8.9 \times 10^{-4}$	CL=90%	2631
$\rho^+\pi^0$	$(1.09 \pm 0.14) \times 10^{-5}$		2581
$\pi^+\pi^-\pi^+\pi^0$	$< 4.0 \times 10^{-3}$	CL=90%	2622
$\rho^+\rho^0$	$(2.40 \pm 0.19) \times 10^{-5}$		2523
$\rho^+ f_0(980),\ f_0 \to \pi^+\pi^-$	$< 2.0 \times 10^{-6}$	CL=90%	2486
$a_1(1260)^+\pi^0$	$(2.6 \pm 0.7) \times 10^{-5}$		2494
$a_1(1260)^0\pi^+$	$(2.0 \pm 0.6) \times 10^{-5}$		2494
$\omega\pi^+$	$(6.9 \pm 0.5) \times 10^{-6}$		2580
$\omega\rho^+$	$(1.59 \pm 0.21) \times 10^{-5}$		2522
$\eta\pi^+$	$(4.02 \pm 0.27) \times 10^{-6}$		2609
$\eta\rho^+$	$(7.0 \pm 2.9) \times 10^{-6}$	S=2.8	2553
$\eta'\pi^+$	$(2.7 \pm 0.9) \times 10^{-6}$	S=1.9	2551
$\eta'\rho^+$	$(9.7 \pm 2.2) \times 10^{-6}$		2492
$\phi\pi^+$	$(3.2 \pm 1.5) \times 10^{-8}$		2539
$\phi\rho^+$	$< 3.0 \times 10^{-6}$	CL=90%	2480

$a_0(980)^0\pi^+$, $a_0^0 \to \eta\pi^0$	<	5.8	$\times 10^{-6}$	CL=90%	–
$a_0(980)^+\pi^0$, $a_0^+ \to \eta\pi^+$	<	1.4	$\times 10^{-6}$	CL=90%	–
$\pi^+\pi^+\pi^+\pi^-\pi^-$	<	8.6	$\times 10^{-4}$	CL=90%	2608
$\rho^0 a_1(1260)^+$	<	6.2	$\times 10^{-4}$	CL=90%	2433
$\rho^0 a_2(1320)^+$	<	7.2	$\times 10^{-4}$	CL=90%	2411
$b_1^0\pi^+$, $b_1^0 \to \omega\pi^0$		(6.7 ± 2.0)	$\times 10^{-6}$		–
$b_1^+\pi^0$, $b_1^+ \to \omega\pi^+$	<	3.3	$\times 10^{-6}$	CL=90%	–
$\pi^+\pi^+\pi^+\pi^-\pi^-\pi^0$	<	6.3	$\times 10^{-3}$	CL=90%	2592
$b_1^+\rho^0$, $b_1^+ \to \omega\pi^+$	<	5.2	$\times 10^{-6}$	CL=90%	–
$a_1(1260)^+ a_1(1260)^0$	<	1.3	%	CL=90%	2336
$b_1^0\rho^+$, $b_1^0 \to \omega\pi^0$	<	3.3	$\times 10^{-6}$	CL=90%	–

Charged particle ($h^\pm$) modes

$h^\pm = K^\pm$ or $\pi^\pm$

$h^+\pi^0$		($1.6\ ^{+0.7}_{-0.6}$)	$\times 10^{-5}$		2636
ωh^+		($1.38\ ^{+0.27}_{-0.24}$)	$\times 10^{-5}$		2580
h^+X^0 (Familon)	<	4.9	$\times 10^{-5}$	CL=90%	–
K^+X^0, $X^0 \to \mu^+\mu^-$	<	1	$\times 10^{-7}$	CL=95%	–

Baryon modes

$p\overline{p}\pi^+$		(1.62 ± 0.20)	$\times 10^{-6}$		2439
$p\overline{p}\pi^+$ nonresonant	<	5.3	$\times 10^{-5}$	CL=90%	2439
$p\overline{p}K^+$		(5.9 ± 0.5)	$\times 10^{-6}$	S=1.5	2348
$\Theta(1710)^{++}\overline{p}$, $\Theta^{++} \to pK^+$ [sss]	<	9.1	$\times 10^{-8}$	CL=90%	–
$f_J(2220)K^+$, $f_J \to p\overline{p}$ [sss]	<	4.1	$\times 10^{-7}$	CL=90%	2135
$p\overline{\Lambda}(1520)$		(3.1 ± 0.6)	$\times 10^{-7}$		2322
$p\overline{p}K^+$ nonresonant	<	8.9	$\times 10^{-5}$	CL=90%	2348
$p\overline{p}K^*(892)^+$		($3.6\ ^{+0.8}_{-0.7}$)	$\times 10^{-6}$		2215
$f_J(2220)K^{*+}$, $f_J \to p\overline{p}$	<	7.7	$\times 10^{-7}$	CL=90%	2059
$p\overline{\Lambda}$		($2.4\ ^{+1.0}_{-0.9}$)	$\times 10^{-7}$		2430
$p\overline{\Lambda}\gamma$		($2.4\ ^{+0.5}_{-0.4}$)	$\times 10^{-6}$		2430
$p\overline{\Lambda}\pi^0$		($3.0\ ^{+0.7}_{-0.6}$)	$\times 10^{-6}$		2402
$p\overline{\Sigma}(1385)^0$	<	4.7	$\times 10^{-7}$	CL=90%	2362
$\Delta^+\overline{\Lambda}$	<	8.2	$\times 10^{-7}$	CL=90%	–
$p\overline{\Sigma}\gamma$	<	4.6	$\times 10^{-6}$	CL=90%	2413
$p\overline{\Lambda}\pi^+\pi^-$		(1.13 ± 0.13)	$\times 10^{-5}$		2367
$p\overline{\Lambda}\pi^+\pi^-$ nonresonant		(5.9 ± 1.1)	$\times 10^{-6}$		2367
$p\overline{\Lambda}\rho^0$, $\rho^0 \to \pi^+\pi^-$		(4.8 ± 0.9)	$\times 10^{-6}$		2214
$p\overline{\Lambda}f_2(1270)$, $f_2 \to \pi^+\pi^-$		(2.0 ± 0.8)	$\times 10^{-6}$		2026
$p\overline{\Lambda}K^+K^-$		(4.1 ± 0.7)	$\times 10^{-6}$		2132
$p\overline{\Lambda}\phi$		(8.0 ± 2.2)	$\times 10^{-7}$		2119
$\overline{p}\Lambda K^+K^-$		(3.7 ± 0.6)	$\times 10^{-6}$		2132
$\Lambda\overline{\Lambda}\pi^+$	<	9.4	$\times 10^{-7}$	CL=90%	2358
$\Lambda\overline{\Lambda}K^+$		(3.4 ± 0.6)	$\times 10^{-6}$		2251
$\Lambda\overline{\Lambda}K^{*+}$		($2.2\ ^{+1.2}_{-0.9}$)	$\times 10^{-6}$		2098
$\Lambda(1520)\overline{\Lambda}K^+$		(2.2 ± 0.7)	$\times 10^{-6}$		2126
$\Lambda\overline{\Lambda}(1520)K^+$	<	2.08	$\times 10^{-6}$		2126
$\overline{\Delta}^0 p$	<	1.38	$\times 10^{-6}$	CL=90%	2403
$\Delta^{++}\overline{p}$	<	1.4	$\times 10^{-7}$	CL=90%	2403
$D^+p\overline{p}$	<	1.5	$\times 10^{-5}$	CL=90%	1860

$D^*(2010)^+ p\overline{p}$		$< 1.5 \times 10^{-5}$	CL=90%	1786
$\overline{D}^0 p\overline{p}\pi^+$		$(3.72 \pm 0.27) \times 10^{-4}$		1789
$\overline{D}^{*0} p\overline{p}\pi^+$		$(3.73 \pm 0.32) \times 10^{-4}$		1709
$D^- p\overline{p}\pi^+\pi^-$		$(1.66 \pm 0.30) \times 10^{-4}$		1705
$D^{*-} p\overline{p}\pi^+\pi^-$		$(1.86 \pm 0.25) \times 10^{-4}$		1621
$p\overline{\Lambda}^0\overline{D}^0$		$(1.43 \pm 0.32) \times 10^{-5}$		–
$p\overline{\Lambda}^0\overline{D}^*(2007)^0$		$< 5 \times 10^{-5}$	CL=90%	–
$\overline{\Lambda}_c^- p\pi^+$		$(2.3 \pm 0.4) \times 10^{-4}$	S=2.2	1980
$\overline{\Lambda}_c^- \Delta(1232)^{++}$		$< 1.9 \times 10^{-5}$	CL=90%	1928
$\overline{\Lambda}_c^- \Delta_X(1600)^{++}$		$(4.7 \pm 1.0) \times 10^{-5}$		–
$\overline{\Lambda}_c^- \Delta_X(2420)^{++}$		$(3.7 \pm 0.8) \times 10^{-5}$		–
$(\overline{\Lambda}_c^- p)_s \pi^+$	[ttt]	$(3.1 \pm 0.7) \times 10^{-5}$		–
$\overline{\Sigma}_c(2520)^0 p$		$< 3 \times 10^{-6}$	CL=90%	1904
$\overline{\Sigma}_c(2800)^0 p$		$(2.6 \pm 0.9) \times 10^{-5}$		–
$\overline{\Lambda}_c^- p\pi^+\pi^0$		$(1.8 \pm 0.6) \times 10^{-3}$		1935
$\overline{\Lambda}_c^- p\pi^+\pi^+\pi^-$		$(2.2 \pm 0.7) \times 10^{-3}$		1880
$\overline{\Lambda}_c^- p\pi^+\pi^+\pi^-\pi^0$		< 1.34 %	CL=90%	1823
$\Lambda_c^+\Lambda_c^- K^+$		$(4.9 \pm 0.7) \times 10^{-4}$		739
$\Xi_c(2930)\Lambda_c^+$, $\Xi_c \to K^+\Lambda_c^-$		$(1.7 \pm 0.5) \times 10^{-4}$		–
$\overline{\Sigma}_c(2455)^0 p$		$(2.9 \pm 0.7) \times 10^{-5}$		1938
$\overline{\Sigma}_c(2455)^0 p\pi^0$		$(3.5 \pm 1.1) \times 10^{-4}$		1896
$\overline{\Sigma}_c(2455)^0 p\pi^-\pi^+$		$(3.5 \pm 1.1) \times 10^{-4}$		1845
$\overline{\Sigma}_c(2455)^{--} p\pi^+\pi^+$		$(2.37 \pm 0.20) \times 10^{-4}$		1845
$\overline{\Lambda}_c(2593)^- / \overline{\Lambda}_c(2625)^- p\pi^+$		$< 1.9 \times 10^{-4}$	CL=90%	–
$\Xi_c^0\Lambda_c^+$		$(9.5 \pm 2.3) \times 10^{-4}$		1144
$\Xi_c^0\Lambda_c^+$, $\Xi_c^0 \to \Xi^+\pi^-$		$(1.76 \pm 0.29) \times 10^{-5}$		1144
$\Xi_c^0\Lambda_c^+$, $\Xi_c^0 \to \Lambda K^+\pi^-$		$(1.14 \pm 0.26) \times 10^{-5}$		1144
$\Xi_c^0\Lambda_c^+$, $\Xi_c^0 \to pK^-K^-\pi^+$		$(5.5 \pm 1.9) \times 10^{-6}$		–
$\Lambda_c^+\Xi_c^{\prime 0}$		$< 6.5 \times 10^{-4}$	CL=90%	1023
$\Lambda_c^+\Xi_c(2645)^0$		$< 7.9 \times 10^{-4}$	CL=90%	–
$\Lambda_c^+\Xi_c(2790)^0$		$(1.1 \pm 0.4) \times 10^{-3}$		–

Lepton Family number (*LF*) or Lepton number (*L*) or Baryon number (*B*) violating modes, or/and $\Delta B = 1$ weak neutral current (*B1*) modes

$\pi^+\ell^+\ell^-$	*B1*		$< 4.9 \times 10^{-8}$	CL=90%	2638
$\pi^+ e^+ e^-$	*B1*		$< 8.0 \times 10^{-8}$	CL=90%	2638
$\pi^+\mu^+\mu^-$	*B1*		$(1.75 \pm 0.22) \times 10^{-8}$		2634
$\pi^+\nu\overline{\nu}$	*B1*		$< 1.4 \times 10^{-5}$	CL=90%	2638
$K^+\ell^+\ell^-$	*B1*	[*lll*]	$(4.51 \pm 0.23) \times 10^{-7}$	S=1.1	2617
$K^+ e^+ e^-$	*B1*		$(5.5 \pm 0.7) \times 10^{-7}$		2617
$K^+\mu^+\mu^-$	*B1*		$(4.41 \pm 0.22) \times 10^{-7}$	S=1.2	2612
$K^+\mu^+\mu^-$ nonresonant	*B1*		$(4.37 \pm 0.27) \times 10^{-7}$		2612
$K^+\tau^+\tau^-$	*B1*		$< 2.25 \times 10^{-3}$	CL=90%	1687
$K^+\overline{\nu}\nu$	*B1*		$< 1.6 \times 10^{-5}$	CL=90%	2617
$\rho^+\nu\overline{\nu}$	*B1*		$< 3.0 \times 10^{-5}$	CL=90%	2583
$K^*(892)^+\ell^+\ell^-$	*B1*	[*lll*]	$(1.01 \pm 0.11) \times 10^{-6}$	S=1.1	2564
$K^*(892)^+ e^+ e^-$	*B1*		$(1.55 {}^{+0.40}_{-0.31}) \times 10^{-6}$		2564
$K^*(892)^+\mu^+\mu^-$	*B1*		$(9.6 \pm 1.0) \times 10^{-7}$		2560
$K^*(892)^+\nu\overline{\nu}$	*B1*		$< 4.0 \times 10^{-5}$	CL=90%	2564
$K^+\pi^+\pi^-\mu^+\mu^-$	*B1*		$(4.3 \pm 0.4) \times 10^{-7}$		2593
$\phi K^+\mu^+\mu^-$	*B1*		$(7.9 {}^{+2.1}_{-1.7}) \times 10^{-8}$		2490
$\overline{\Lambda} p\nu\overline{\nu}$			$< 3.0 \times 10^{-5}$	CL=90%	2430

$\pi^+ e^+ \mu^-$	*LF*	<	6.4	$\times 10^{-3}$	CL=90%	2637
$\pi^+ e^- \mu^+$	*LF*	<	6.4	$\times 10^{-3}$	CL=90%	2637
$\pi^+ e^\pm \mu^\mp$	*LF*	<	1.7	$\times 10^{-7}$	CL=90%	2637
$\pi^+ e^+ \tau^-$	*LF*	<	7.4	$\times 10^{-5}$	CL=90%	2338
$\pi^+ e^- \tau^+$	*LF*	<	2.0	$\times 10^{-5}$	CL=90%	2338
$\pi^+ e^\pm \tau^\mp$	*LF*	<	7.5	$\times 10^{-5}$	CL=90%	2338
$\pi^+ \mu^+ \tau^-$	*LF*	<	6.2	$\times 10^{-5}$	CL=90%	2333
$\pi^+ \mu^- \tau^+$	*LF*	<	4.5	$\times 10^{-5}$	CL=90%	2333
$\pi^+ \mu^\pm \tau^\mp$	*LF*	<	7.2	$\times 10^{-5}$	CL=90%	2333
$K^+ e^+ \mu^-$	*LF*	<	7.0	$\times 10^{-9}$	CL=90%	2615
$K^+ e^- \mu^+$	*LF*	<	6.4	$\times 10^{-9}$	CL=90%	2615
$K^+ e^\pm \mu^\mp$	*LF*	<	9.1	$\times 10^{-8}$	CL=90%	2615
$K^+ e^+ \tau^-$	*LF*	<	4.3	$\times 10^{-5}$	CL=90%	2312
$K^+ e^- \tau^+$	*LF*	<	1.5	$\times 10^{-5}$	CL=90%	2312
$K^+ e^\pm \tau^\mp$	*LF*	<	3.0	$\times 10^{-5}$	CL=90%	2312
$K^+ \mu^+ \tau^-$	*LF*	<	4.5	$\times 10^{-5}$	CL=90%	2298
$K^+ \mu^- \tau^+$	*LF*	<	2.8	$\times 10^{-5}$	CL=90%	2298
$K^+ \mu^\pm \tau^\mp$	*LF*	<	4.8	$\times 10^{-5}$	CL=90%	2298
$K^*(892)^+ e^+ \mu^-$	*LF*	<	1.3	$\times 10^{-6}$	CL=90%	2563
$K^*(892)^+ e^- \mu^+$	*LF*	<	9.9	$\times 10^{-7}$	CL=90%	2563
$K^*(892)^+ e^\pm \mu^\mp$	*LF*	<	1.4	$\times 10^{-6}$	CL=90%	2563
$\pi^- e^+ e^+$	*L*	<	2.3	$\times 10^{-8}$	CL=90%	2638
$\pi^- \mu^+ \mu^+$	*L*	<	4.0	$\times 10^{-9}$	CL=95%	2634
$\pi^- e^+ \mu^+$	*L*	<	1.5	$\times 10^{-7}$	CL=90%	2637
$\rho^- e^+ e^+$	*L*	<	1.7	$\times 10^{-7}$	CL=90%	2583
$\rho^- \mu^+ \mu^+$	*L*	<	4.2	$\times 10^{-7}$	CL=90%	2578
$\rho^- e^+ \mu^+$	*L*	<	4.7	$\times 10^{-7}$	CL=90%	2582
$K^- e^+ e^+$	*L*	<	3.0	$\times 10^{-8}$	CL=90%	2617
$K^- \mu^+ \mu^+$	*L*	<	4.1	$\times 10^{-8}$	CL=90%	2612
$K^- e^+ \mu^+$	*L*	<	1.6	$\times 10^{-7}$	CL=90%	2615
$K^*(892)^- e^+ e^+$	*L*	<	4.0	$\times 10^{-7}$	CL=90%	2564
$K^*(892)^- \mu^+ \mu^+$	*L*	<	5.9	$\times 10^{-7}$	CL=90%	2560
$K^*(892)^- e^+ \mu^+$	*L*	<	3.0	$\times 10^{-7}$	CL=90%	2563
$D^- e^+ e^+$	*L*	<	2.6	$\times 10^{-6}$	CL=90%	2309
$D^- e^+ \mu^+$	*L*	<	1.8	$\times 10^{-6}$	CL=90%	2307
$D^- \mu^+ \mu^+$	*L*	<	6.9	$\times 10^{-7}$	CL=95%	2303
$D^{*-} \mu^+ \mu^+$	*L*	<	2.4	$\times 10^{-6}$	CL=95%	2251
$D_s^- \mu^+ \mu^+$	*L*	<	5.8	$\times 10^{-7}$	CL=95%	2267
$\overline{D}^0 \pi^- \mu^+ \mu^+$	*L*	<	1.5	$\times 10^{-6}$	CL=95%	2295
$\Lambda^0 \mu^+$	*L,B*	<	6	$\times 10^{-8}$	CL=90%	–
$\Lambda^0 e^+$	*L,B*	<	3.2	$\times 10^{-8}$	CL=90%	–
$\overline{\Lambda}^0 \mu^+$	*L,B*	<	6	$\times 10^{-8}$	CL=90%	–
$\overline{\Lambda}^0 e^+$	*L,B*	<	8	$\times 10^{-8}$	CL=90%	–

See Particle Listings for 15 decay modes that have been seen / not seen.

B^0

$I(J^P) = \frac{1}{2}(0^-)$

I, *J*, *P* need confirmation. Quantum numbers shown are quark-model predictions.

Mass $m_{B^0} = 5279.65 \pm 0.12$ MeV

$m_{B^0} - m_{B^\pm} = 0.31 \pm 0.05$ MeV

Mean life $\tau_{B^0} = (1.519 \pm 0.004) \times 10^{-12}$ s

$c\tau = 455.4\ \mu$m

$\tau_{B^+}/\tau_{B^0} = 1.076 \pm 0.004$ (direct measurements)

B^0-$\overline{B}^0$ mixing parameters

$\chi_d = 0.1858 \pm 0.0011$
$\Delta m_{B^0} = m_{B^0_H} - m_{B^0_L} = (0.5065 \pm 0.0019) \times 10^{12}\ \hbar\ s^{-1}$
$= (3.334 \pm 0.013) \times 10^{-10}$ MeV
$x_d = \Delta m_{B^0}/\Gamma_{B^0} = 0.769 \pm 0.004$
$\text{Re}(\lambda_{CP} / |\lambda_{CP}|)\ \text{Re}(z) = 0.047 \pm 0.022$
$\Delta\Gamma\ \text{Re}(z) = -0.007 \pm 0.004$
$\text{Re}(z) = (-4 \pm 4) \times 10^{-2}$ (S = 1.4)
$\text{Im}(z) = (-0.8 \pm 0.4) \times 10^{-2}$

CP violation parameters

$\text{Re}(\epsilon_{B^0})/(1+|\epsilon_{B^0}|^2) = (-0.5 \pm 0.4) \times 10^{-3}$
$A_{T/CP}(B^0 \leftrightarrow \overline{B}^0) = 0.005 \pm 0.018$
$A_{CP}(B^0 \to D^*(2010)^+ D^-) = 0.037 \pm 0.034$
$A_{CP}(B^0 \to [K^+ K^-]_D K^*(892)^0) = -0.05 \pm 0.10$
$A_{CP}(B^0 \to [K^+ \pi^-]_D K^*(892)^0) = 0.047 \pm 0.029$
$A_{CP}(B^0 \to [K^+ \pi^- \pi^+ \pi^-]_D K^*(892)^0) = 0.037 \pm 0.034$
$A_{CP}(B^0 \to [K^- \pi^+]_D K^*(892)^0) = 0.19 \pm 0.19$
$A_{CP}(B^0 \to [K^- \pi^+ \pi^+ \pi^-]_D K^*(892)^0) = -0.01 \pm 0.24$
$R_d^+ = \Gamma(B^0 \to [\pi^+ K^-]_D K^{*0}) / \Gamma(B^0 \to [\pi^- K^+]_D K^{*0}) = 0.064 \pm 0.021$
$R_d^- = \Gamma(\overline{B}^0 \to [\pi^- K^+]_D K^{*0}) / \Gamma(\overline{B}^0 \to [\pi^+ K^-]_D K^{*0}) = 0.095 \pm 0.021$
$A_{CP}(B^0 \to [\pi^+ \pi^-]_D K^*(892)^0) = -0.18 \pm 0.14$
$A_{CP}(B^0 \to [\pi^+ \pi^- \pi^+ \pi^-]_D K^*(892)^0) = -0.03 \pm 0.15$
$R_d^+ = \Gamma(B^0 \to [\pi^+ K^- \pi^+ \pi^-]_D K^{*0}) / \Gamma(B^0 \to [\pi^- K^+ \pi^+ \pi^-]_D K^{*0}) = 0.074 \pm 0.026$
$R_d^- = \Gamma(\overline{B}^0 \to [\pi^- K^+ \pi^+ \pi^-]_D K^{*0}) / \Gamma(\overline{B}^0 \to [\pi^+ K^- \pi^+ \pi^-]_D K^{*0}) = 0.072 \pm 0.025$
$\boldsymbol{A_{CP}(B^0 \to K^+ \pi^-)} = -0.083 \pm 0.004$
$A_{CP}(B^0 \to \eta' K^*(892)^0) = -0.07 \pm 0.18$
$A_{CP}(B^0 \to \eta' K_0^*(1430)^0) = -0.19 \pm 0.17$
$A_{CP}(B^0 \to \eta' K_2^*(1430)^0) = 0.14 \pm 0.18$
$\boldsymbol{A_{CP}(B^0 \to \eta K^*(892)^0)} = 0.19 \pm 0.05$
$A_{CP}(B^0 \to \eta K_0^*(1430)^0) = 0.06 \pm 0.13$
$A_{CP}(B^0 \to \eta K_2^*(1430)^0) = -0.07 \pm 0.19$
$A_{CP}(B^0 \to b_1 K^+) = -0.07 \pm 0.12$
$A_{CP}(B^0 \to \omega K^{*0}) = 0.45 \pm 0.25$
$A_{CP}(B^0 \to \omega (K\pi)_0^{*0}) = -0.07 \pm 0.09$
$A_{CP}(B^0 \to \omega K_2^*(1430)^0) = -0.37 \pm 0.17$
$A_{CP}(B^0 \to K^+ \pi^- \pi^0) = (0 \pm 6) \times 10^{-2}$
$A_{CP}(B^0 \to \rho^- K^+) = 0.20 \pm 0.11$
$A_{CP}(B^0 \to \rho(1450)^- K^+) = -0.10 \pm 0.33$
$A_{CP}(B^0 \to \rho(1700)^- K^+) = -0.4 \pm 0.6$
$A_{CP}(B^0 \to K^+ \pi^- \pi^0\ \text{nonresonant}) = 0.10 \pm 0.18$
$A_{CP}(B^0 \to K^0 \pi^+ \pi^-) = -0.01 \pm 0.05$
$\boldsymbol{A_{CP}(B^0 \to K^*(892)^+ \pi^-)} = -0.27 \pm 0.04$
$A_{CP}(B^0 \to (K\pi)_0^{*+} \pi^-) = 0.02 \pm 0.04$
$A_{CP}(B^0 \to K_2^*(1430)^+ \pi^-) = -0.29 \pm 0.24$
$A_{CP}(B^0 \to K^*(1680)^+ \pi^-) = -0.07 \pm 0.14$
$A_{CP}(B^0 \to f_0(980) K_S^0) = 0.28 \pm 0.31$

$A_{CP}(B^0 \to (K\pi)_0^{*0}\pi^0) = -0.15 \pm 0.11$
$A_{CP}(B^0 \to K^{*0}\pi^0) = -0.15 \pm 0.13$
$A_{CP}(B^0 \to K^*(892)^0\pi^+\pi^-) = 0.07 \pm 0.05$
$A_{CP}(B^0 \to K^*(892)^0\rho^0) = -0.06 \pm 0.09$
$A_{CP}(B^0 \to K^{*0}f_0(980)) = 0.07 \pm 0.10$
$A_{CP}(B^0 \to K^{*+}\rho^-) = 0.21 \pm 0.15$
$A_{CP}(B^0 \to K^*(892)^0K^+K^-) = 0.01 \pm 0.05$
$A_{CP}(B^0 \to a_1^- K^+) = -0.16 \pm 0.12$
$A_{CP}(B^0 \to K^0 K^0) = -0.6 \pm 0.7$
$A_{CP}(B^0 \to K^*(892)^0\phi) = 0.00 \pm 0.04$
$A_{CP}(B^0 \to K^*(892)^0K^-\pi^+) = 0.2 \pm 0.4$
$A_{CP}(B^0 \to \phi(K\pi)_0^{*0}) = 0.12 \pm 0.08$
$A_{CP}(B^0 \to \phi K_2^*(1430)^0) = -0.11 \pm 0.10$
$A_{CP}(B^0 \to K^*(892)^0\gamma) = -0.006 \pm 0.011$
$A_{CP}(B^0 \to K_2^*(1430)^0\gamma) = -0.08 \pm 0.15$
$A_{CP}(B^0 \to X_s\gamma) = -0.009 \pm 0.018$
$A_{CP}(B^0 \to \rho^+\pi^-) = 0.13 \pm 0.06$ (S = 1.1)
$A_{CP}(B^0 \to \rho^-\pi^+) = -0.08 \pm 0.08$
$A_{CP}(B^0 \to a_1(1260)^\pm\pi^\mp) = -0.07 \pm 0.06$
$A_{CP}(B^0 \to b_1^-\pi^+) = -0.05 \pm 0.10$
$A_{CP}(B^0 \to p\overline{p}K^*(892)^0) = 0.05 \pm 0.12$
$A_{CP}(B^0 \to p\overline{\Lambda}\pi^-) = 0.04 \pm 0.07$
$A_{CP}(B^0 \to K^{*0}\ell^+\ell^-) = -0.05 \pm 0.10$
$A_{CP}(B^0 \to K^{*0}e^+e^-) = -0.21 \pm 0.19$
$A_{CP}(B^0 \to K^{*0}\mu^+\mu^-) = -0.034 \pm 0.024$
$C_{D^{*-}D^+}(B^0 \to D^*(2010)^-D^+) = -0.01 \pm 0.11$
$\boldsymbol{S_{D^{*-}D^+}(B^0 \to D^*(2010)^-D^+)} = -0.72 \pm 0.15$
$C_{D^{*+}D^-}(B^0 \to D^*(2010)^+D^-) = 0.00 \pm 0.13$ (S = 1.3)
$\boldsymbol{S_{D^{*+}D^-}(B^0 \to D^*(2010)^+D^-)} = -0.73 \pm 0.14$
$C_{D^{*+}D^{*-}}(B^0 \to D^{*+}D^{*-}) = 0.01 \pm 0.09$ (S = 1.6)
$\boldsymbol{S_{D^{*+}D^{*-}}(B^0 \to D^{*+}D^{*-})} = -0.59 \pm 0.14$ (S = 1.8)
$C_+(B^0 \to D^{*+}D^{*-}) = 0.00 \pm 0.10$ (S = 1.6)
$\boldsymbol{S_+(B^0 \to D^{*+}D^{*-})} = -0.73 \pm 0.09$
$C_-(B^0 \to D^{*+}D^{*-}) = 0.19 \pm 0.31$
$S_-(B^0 \to D^{*+}D^{*-}) = 0.1 \pm 1.6$ (S = 3.5)
$C(B^0 \to D^*(2010)^+D^*(2010)^-K_S^0) = 0.01 \pm 0.29$
$S(B^0 \to D^*(2010)^+D^*(2010)^-K_S^0) = 0.1 \pm 0.4$
$C_{D^+D^-}(B^0 \to D^+D^-) = -0.22 \pm 0.24$ (S = 2.5)
$\boldsymbol{S_{D^+D^-}(B^0 \to D^+D^-)} = -0.76^{+0.15}_{-0.13}$ (S = 1.2)
$C_{J/\psi(1S)\pi^0}(B^0 \to J/\psi(1S)\pi^0) = 0.03 \pm 0.17$ (S = 1.5)
$\boldsymbol{S_{J/\psi(1S)\pi^0}(B^0 \to J/\psi(1S)\pi^0)} = -0.88 \pm 0.32$ (S = 2.2)
$C(B^0 \to J/\psi(1S)\rho^0) = -0.06 \pm 0.06$
$\boldsymbol{S(B^0 \to J/\psi(1S)\rho^0)} = -0.66^{+0.16}_{-0.12}$
$C_{D^{(*)}_{CP}h^0}(B^0 \to D^{(*)}_{CP}h^0) = -0.02 \pm 0.08$
$\boldsymbol{S_{D^{(*)}_{CP}h^0}(B^0 \to D^{(*)}_{CP}h^0)} = -0.66 \pm 0.12$
$C_{K^0\pi^0}(B^0 \to K^0\pi^0) = 0.00 \pm 0.13$ (S = 1.4)
$\boldsymbol{S_{K^0\pi^0}(B^0 \to K^0\pi^0)} = 0.58 \pm 0.17$
$C_{\eta'(958)K_S^0}(B^0 \to \eta'(958)K_S^0) = -0.04 \pm 0.20$ (S = 2.5)
$S_{\eta'(958)K_S^0}(B^0 \to \eta'(958)K_S^0) = 0.43 \pm 0.17$ (S = 1.5)

$C_{\eta' K^0}$ $(B^0 \to \eta' K^0) = -0.06 \pm 0.04$
$\boldsymbol{S_{\eta' K^0}}$ $\boldsymbol{(B^0 \to \eta' K^0)} = 0.63 \pm 0.06$
$C_{\omega K^0_S}$ $(B^0 \to \omega K^0_S) = 0.0 \pm 0.4$ (S = 3.0)
$S_{\omega K^0_S}$ $(B^0 \to \omega K^0_S) = 0.70 \pm 0.21$
$C\,(B^0 \to K^0_S \pi^0 \pi^0) = -0.21 \pm 0.20$
$S\,(B^0 \to K^0_S \pi^0 \pi^0) = 0.89^{+0.27}_{-0.30}$
$C_{\rho^0 K^0_S}$ $(B^0 \to \rho^0 K^0_S) = -0.04 \pm 0.20$
$S_{\rho^0 K^0_S}$ $(B^0 \to \rho^0 K^0_S) = 0.50^{+0.17}_{-0.21}$
$C_{f_0 K^0_S}$ $(B^0 \to f_0(980) K^0_S) = 0.29 \pm 0.20$
$\boldsymbol{S_{f_0 K^0_S}}$ $\boldsymbol{(B^0 \to f_0(980) K^0_S)} = -0.50 \pm 0.16$
$S_{f_2 K^0_S}$ $(B^0 \to f_2(1270) K^0_S) = -0.5 \pm 0.5$
$C_{f_2 K^0_S}$ $(B^0 \to f_2(1270) K^0_S) = 0.3 \pm 0.4$
$S_{f_x K^0_S}$ $(B^0 \to f_x(1300) K^0_S) = -0.2 \pm 0.5$
$C_{f_x K^0_S}$ $(B^0 \to f_x(1300) K^0_S) = 0.13 \pm 0.35$
$S_{K^0 \pi^+ \pi^-}$ $(B^0 \to K^0 \pi^+ \pi^-$ nonresonant$) = -0.01 \pm 0.33$
$C_{K^0 \pi^+ \pi^-}$ $(B^0 \to K^0 \pi^+ \pi^-$ nonresonant$) = 0.01 \pm 0.26$
$C_{K^0_S K^0_S}$ $(B^0 \to K^0_S K^0_S) = 0.0 \pm 0.4$ (S = 1.4)
$S_{K^0_S K^0_S}$ $(B^0 \to K^0_S K^0_S) = -0.8 \pm 0.5$
$C_{K^+ K^- K^0_S}$ $(B^0 \to K^+ K^- K^0_S$ nonresonant$) = 0.06 \pm 0.08$
$\boldsymbol{S_{K^+ K^- K^0_S}}$ $\boldsymbol{(B^0 \to K^+ K^- K^0_S}$ **nonresonant)** $= -0.66 \pm 0.11$
$C_{K^+ K^- K^0_S}$ $(B^0 \to K^+ K^- K^0_S$ inclusive$) = 0.01 \pm 0.09$
$\boldsymbol{S_{K^+ K^- K^0_S}}$ $\boldsymbol{(B^0 \to K^+ K^- K^0_S}$ **inclusive)** $= -0.65 \pm 0.12$
$C_{\phi K^0_S}$ $(B^0 \to \phi K^0_S) = 0.01 \pm 0.14$
$\boldsymbol{S_{\phi K^0_S}}$ $\boldsymbol{(B^0 \to \phi K^0_S)} = 0.59 \pm 0.14$
$C_{K_S K_S K_S}(B^0 \to K_S K_S K_S) = -0.23 \pm 0.14$
$S_{K_S K_S K_S}(B^0 \to K_S K_S K_S) = -0.5 \pm 0.6$ (S = 3.0)
$C_{K^0_S \pi^0 \gamma}(B^0 \to K^0_S \pi^0 \gamma) = 0.36 \pm 0.33$
$S_{K^0_S \pi^0 \gamma}(B^0 \to K^0_S \pi^0 \gamma) = -0.8 \pm 0.6$
$C_{K^0_S \pi^+ \pi^- \gamma}(B^0 \to K^0_S \pi^+ \pi^- \gamma) = -0.39 \pm 0.20$
$S_{K^0_S \pi^+ \pi^- \gamma}(B^0 \to K^0_S \pi^+ \pi^- \gamma) = 0.14 \pm 0.25$
$C_{K^{*0} \gamma}$ $(B^0 \to K^*(892)^0 \gamma) = -0.04 \pm 0.16$ (S = 1.2)
$S_{K^{*0} \gamma}$ $(B^0 \to K^*(892)^0 \gamma) = -0.15 \pm 0.22$
$C_{\eta K^0 \gamma}$ $(B^0 \to \eta K^0 \gamma) = 0.1 \pm 0.4$ (S = 1.4)
$S_{\eta K^0 \gamma}$ $(B^0 \to \eta K^0 \gamma) = -0.5 \pm 0.5$ (S = 1.2)
$C_{K^0 \phi \gamma}$ $(B^0 \to K^0 \phi \gamma) = -0.3 \pm 0.6$
$S_{K^0 \phi \gamma}$ $(B^0 \to K^0 \phi \gamma) = 0.7^{+0.7}_{-1.1}$
$C(B^0 \to K^0_S \rho^0 \gamma) = -0.05 \pm 0.19$
$S(B^0 \to K^0_S \rho^0 \gamma) = -0.04 \pm 0.23$
$C\,(B^0 \to \rho^0 \gamma) = 0.4 \pm 0.5$
$S\,(B^0 \to \rho^0 \gamma) = -0.8 \pm 0.7$
$\boldsymbol{C_{\pi\pi}}$ $\boldsymbol{(B^0 \to \pi^+ \pi^-)} = -0.32 \pm 0.04$
$\boldsymbol{S_{\pi\pi}}$ $\boldsymbol{(B^0 \to \pi^+ \pi^-)} = -0.65 \pm 0.04$

$C_{\pi^0\pi^0}(B^0 \to \pi^0\pi^0) = -0.33 \pm 0.22$
$C_{\rho\pi}$ $(B^0 \to \rho^+\pi^-) = -0.03 \pm 0.07$ (S = 1.2)
$S_{\rho\pi}$ $(B^0 \to \rho^+\pi^-) = 0.05 \pm 0.07$
$\boldsymbol{\Delta C_{\rho\pi}}$ **$(B^0 \to \rho^+\pi^-)$** $= 0.27 \pm 0.06$
$\Delta S_{\rho\pi}$ $(B^0 \to \rho^+\pi^-) = 0.01 \pm 0.08$
$C_{\rho^0\pi^0}$ $(B^0 \to \rho^0\pi^0) = 0.27 \pm 0.24$
$S_{\rho^0\pi^0}$ $(B^0 \to \rho^0\pi^0) = -0.23 \pm 0.34$
$C_{a_1\pi}$ $(B^0 \to a_1(1260)^+\pi^-) = -0.05 \pm 0.11$
$S_{a_1\pi}$ $(B^0 \to a_1(1260)^+\pi^-) = -0.2 \pm 0.4$ (S = 3.2)
$\boldsymbol{\Delta C_{a_1\pi}}$ **$(B^0 \to a_1(1260)^+\pi^-)$** $= 0.43 \pm 0.14$ (S = 1.3)
$\Delta S_{a_1\pi}$ $(B^0 \to a_1(1260)^+\pi^-) = -0.11 \pm 0.12$
C $(B^0 \to b_1^- K^+) = -0.22 \pm 0.24$
$\boldsymbol{\Delta C}$ **$(B^0 \to b_1^-\pi^+)$** $= -1.04 \pm 0.24$
$C_{\rho^0\rho^0}$ $(B^0 \to \rho^0\rho^0) = 0.2 \pm 0.9$
$S_{\rho^0\rho^0}$ $(B^0 \to \rho^0\rho^0) = 0.3 \pm 0.7$
$C_{\rho\rho}$ $(B^0 \to \rho^+\rho^-) = 0.00 \pm 0.09$
$S_{\rho\rho}$ $(B^0 \to \rho^+\rho^-) = -0.14 \pm 0.13$
$|\lambda|$ $(B^0 \to J/\psi K^*(892)^0) < 0.25$, CL = 95%
$\cos 2\beta$ $(B^0 \to J/\psi K^*(892)^0) = 1.7^{+0.7}_{-0.9}$ (S = 1.6)
$\cos 2\beta$ $(B^0 \to [K_S^0\pi^+\pi^-]_{D^{(*)}} h^0) = 0.91 \pm 0.25$
$(S_+ + S_-)/2$ $(B^0 \to D^{*-}\pi^+) = -0.039 \pm 0.011$
$(S_- - S_+)/2$ $(B^0 \to D^{*-}\pi^+) = -0.009 \pm 0.015$
$(S_+ + S_-)/2$ $(B^0 \to D^-\pi^+) = -0.046 \pm 0.023$
$(S_- - S_+)/2$ $(B^0 \to D^-\pi^+) = -0.022 \pm 0.021$
S_+ $(B^0 \to D^-\pi^+) = 0.058 \pm 0.023$
S_- $(B^0 \to D^+\pi^-) = 0.038 \pm 0.021$
$(S_+ + S_-)/2$ $(B^0 \to D^-\rho^+) = -0.024 \pm 0.032$
$(S_- - S_+)/2$ $(B^0 \to D^-\rho^+) = -0.10 \pm 0.06$
$C_{\eta_c K_S^0}$ $(B^0 \to \eta_c K_S^0) = 0.08 \pm 0.13$
$\boldsymbol{S_{\eta_c K_S^0}}$ **$(B^0 \to \eta_c K_S^0)$** $= 0.93 \pm 0.17$
$C_{c\overline{c}K^{(*)0}}$ $(B^0 \to c\overline{c}K^{(*)0}) = (0.5 \pm 1.7) \times 10^{-2}$
$\sin(2\beta)$ $= 0.695 \pm 0.019$
$C_{J/\psi(nS)K^0}$ $(B^0 \to J/\psi(nS)K^0) = (0.5 \pm 2.0) \times 10^{-2}$
$\boldsymbol{S_{J/\psi(nS)K^0}}$ **$(B^0 \to J/\psi(nS)K^0)$** $= 0.701 \pm 0.017$
$C_{J/\psi K^{*0}}$ $(B^0 \to J/\psi K^{*0}) = 0.03 \pm 0.10$
$S_{J/\psi K^{*0}}$ $(B^0 \to J/\psi K^{*0}) = 0.60 \pm 0.25$
$C_{\chi_{c0}K_S^0}$ $(B^0 \to \chi_{c0}K_S^0) = -0.3^{+0.5}_{-0.4}$
$S_{\chi_{c0}K_S^0}$ $(B^0 \to \chi_{c0}K_S^0) = -0.7 \pm 0.5$
$C_{\chi_{c1}K_S^0}$ $(B^0 \to \chi_{c1}K_S^0) = 0.06 \pm 0.07$
$\boldsymbol{S_{\chi_{c1}K_S^0}}$ **$(B^0 \to \chi_{c1}K_S^0)$** $= 0.63 \pm 0.10$
$\sin(2\beta_{\rm eff})(B^0 \to \phi K^0) = 0.22 \pm 0.30$
$\sin(2\beta_{\rm eff})(B^0 \to \phi K_0^*(1430)^0) = 0.97^{+0.03}_{-0.52}$
$\sin(2\beta_{\rm eff})(B^0 \to K^+K^-K_S^0)$ $= 0.77^{+0.13}_{-0.12}$
$\sin(2\beta_{\rm eff})(B^0 \to [K_S^0\pi^+\pi^-]_{D^{(*)}} h^0) = 0.80 \pm 0.16$
$\beta_{\rm eff}(B^0 \to [K_S^0\pi^+\pi^-]_{D^{(*)}} h^0) = (22 \pm 5)^\circ$
$2\beta_{\rm eff}(B^0 \to J/\psi\rho^0) = (42^{+10}_{-11})^\circ$

$|\lambda|$ ($B^0 \to [K^0_S \pi^+ \pi^-]_{D^{(*)}} h^0$) = 1.01 ± 0.08
$|\sin(2\beta + \gamma)|$ > 0.40, CL = 90%
$2\beta + \gamma = (83 \pm 60)^\circ$
$\boldsymbol{\alpha} = (84.9^{+5.1}_{-4.5})^\circ$
$x_+(B^0 \to D K^{*0}) = 0.04 \pm 0.17$
$x_-(B^0 \to D K^{*0}) = -0.16 \pm 0.14$
$y_+(B^0 \to D K^{*0}) = -0.68 \pm 0.22$
$y_-(B^0 \to D K^{*0}) = 0.20 \pm 0.25$ (S = 1.2)
$\boldsymbol{r_{B^0}(B^0 \to D K^{*0})} = 0.220^{+0.041}_{-0.047}$
$\boldsymbol{\delta_{B^0}(B^0 \to D K^{*0})} = (194^{+30}_{-22})^\circ$

$\overline{B}^0$ modes are charge conjugates of the modes below. Reactions indicate the weak decay vertex and do not include mixing. Modes which do not identify the charge state of the B are listed in the $B^\pm/B^0$ ADMIXTURE section.

The branching fractions listed below assume 50% $B^0\overline{B}^0$ and 50% B^+B^- production at the $\Upsilon(4S)$. We have attempted to bring older measurements up to date by rescaling their assumed $\Upsilon(4S)$ production ratio to 50:50 and their assumed D, D_s, D^*, and ψ branching ratios to current values whenever this would affect our averages and best limits significantly.

Indentation is used to indicate a subchannel of a previous reaction. All resonant subchannels have been corrected for resonance branching fractions to the final state so the sum of the subchannel branching fractions can exceed that of the final state.

For inclusive branching fractions, *e.g.*, $B \to D^\pm X$, the values usually are multiplicities, not branching fractions. They can be greater than one.

B^0 DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\ell^+ \nu_\ell X$	[lll]	(10.33 ± 0.28) %		–
$e^+ \nu_e X_c$		(10.1 ± 0.4) %		–
$D \ell^+ \nu_\ell X$		(9.4 ± 0.9) %		–
$D^- \ell^+ \nu_\ell$	[lll]	(2.31 ± 0.10) %		2309
$D^- \tau^+ \nu_\tau$		(1.08 ± 0.23) %		1909
$D^*(2010)^- \ell^+ \nu_\ell$	[lll]	(5.05 ± 0.14) %		2257
$D^*(2010)^- \tau^+ \nu_\tau$		(1.57 ± 0.09) %	S=1.1	1838
$\overline{D}^0 \pi^- \ell^+ \nu_\ell$		(4.1 ± 0.5) $\times 10^{-3}$		2308
$D_0^*(2300)^- \ell^+ \nu_\ell$, $D_0^{*-} \to \overline{D}^0 \pi^-$		(3.0 ± 1.2) $\times 10^{-3}$	S=1.8	–
$D_2^*(2460)^- \ell^+ \nu_\ell$, $D_2^{*-} \to \overline{D}^0 \pi^-$		(1.21 ± 0.33) $\times 10^{-3}$	S=1.8	2065
$\overline{D}^{(*)} n\pi \ell^+ \nu_\ell (n \geq 1)$		(2.3 ± 0.5) %		–
$\overline{D}^{*0} \pi^- \ell^+ \nu_\ell$		(5.8 ± 0.8) $\times 10^{-3}$	S=1.4	2256
$D_1(2420)^- \ell^+ \nu_\ell$, $D_1^- \to \overline{D}^{*0} \pi^-$		(2.80 ± 0.28) $\times 10^{-3}$		–
$D_1'(2430)^- \ell^+ \nu_\ell$, $D_1'^- \to \overline{D}^{*0} \pi^-$		(3.1 ± 0.9) $\times 10^{-3}$		–
$D_2^*(2460)^- \ell^+ \nu_\ell$, $D_2^{*-} \to \overline{D}^{*0} \pi^-$		(6.8 ± 1.2) $\times 10^{-4}$		2065
$D^- \pi^+ \pi^- \ell^+ \nu_\ell$		(1.3 ± 0.5) $\times 10^{-3}$		2299
$D^{*-} \pi^+ \pi^- \ell^+ \nu_\ell$		(1.4 ± 0.5) $\times 10^{-3}$		2247
$\rho^- \ell^+ \nu_\ell$	[lll]	(2.94 ± 0.21) $\times 10^{-4}$		2583
$\pi^- \ell^+ \nu_\ell$	[lll]	(1.50 ± 0.06) $\times 10^{-4}$		2638
$\pi^- \tau^+ \nu_\tau$		< 2.5 $\times 10^{-4}$	CL=90%	2339

Inclusive modes			
$K^{\pm} X$	(78 ± 8) %		–
$D^0 X$	(8.1 ± 1.5) %		–
$\overline{D}^0 X$	(47.4 ± 2.8) %		–
$D^+ X$	< 3.9 %	CL=90%	–
$D^- X$	(36.9 ± 3.3) %		–
$D_s^+ X$	$(10.3 {}^{+2.1}_{-1.8})$ %		–
$D_s^- X$	< 2.6 %	CL=90%	–
$\Lambda_c^+ X$	< 3.1 %	CL=90%	–
$\overline{\Lambda}_c^- X$	$(5.0 {}^{+2.1}_{-1.5})$ %		–
$\overline{c} X$	(95 ± 5) %		–
$c X$	(24.6 ± 3.1) %		–
$\overline{c}/c X$	(119 ± 6) %		–
D, D^*, or D_s modes			
$D^- \pi^+$	$(2.52 \pm 0.13) \times 10^{-3}$	S=1.1	2306
$D^- \rho^+$	$(7.6 \pm 1.2) \times 10^{-3}$		2235
$D^- K^0 \pi^+$	$(4.9 \pm 0.9) \times 10^{-4}$		2259
$D^- K^*(892)^+$	$(4.5 \pm 0.7) \times 10^{-4}$		2211
$D^- \omega \pi^+$	$(2.8 \pm 0.6) \times 10^{-3}$		2204
$D^- K^+$	$(1.86 \pm 0.20) \times 10^{-4}$		2279
$D^- K^+ \pi^+ \pi^-$	$(3.5 \pm 0.8) \times 10^{-4}$		2236
$D^- K^+ \overline{K}^0$	$< 3.1 \times 10^{-4}$	CL=90%	2188
$D^- K^+ \overline{K}^*(892)^0$	$(8.8 \pm 1.9) \times 10^{-4}$		2070
$\overline{D}^0 \pi^+ \pi^-$	$(8.8 \pm 0.5) \times 10^{-4}$		2301
$D^*(2010)^- \pi^+$	$(2.74 \pm 0.13) \times 10^{-3}$		2255
$\overline{D}^0 K^+ K^-$	$(5.9 \pm 0.5) \times 10^{-5}$		2191
$D^- \pi^+ \pi^+ \pi^-$	$(6.0 \pm 0.7) \times 10^{-3}$	S=1.1	2287
$(D^- \pi^+ \pi^+ \pi^-)$ nonresonant	$(3.9 \pm 1.9) \times 10^{-3}$		2287
$D^- \pi^+ \rho^0$	$(1.1 \pm 1.0) \times 10^{-3}$		2206
$D^- a_1(1260)^+$	$(6.0 \pm 3.3) \times 10^{-3}$		2121
$D^*(2010)^- \pi^+ \pi^0$	(1.5 ± 0.5) %		2248
$D^*(2010)^- \rho^+$	$(6.8 \pm 0.9) \times 10^{-3}$		2180
$D^*(2010)^- K^+$	$(2.12 \pm 0.15) \times 10^{-4}$		2226
$D^*(2010)^- K^0 \pi^+$	$(3.0 \pm 0.8) \times 10^{-4}$		2205
$D^*(2010)^- K^*(892)^+$	$(3.3 \pm 0.6) \times 10^{-4}$		2155
$D^*(2010)^- K^+ \overline{K}^0$	$< 4.7 \times 10^{-4}$	CL=90%	2131
$D^*(2010)^- K^+ \overline{K}^*(892)^0$	$(1.29 \pm 0.33) \times 10^{-3}$		2007
$D^*(2010)^- \pi^+ \pi^+ \pi^-$	$(7.21 \pm 0.29) \times 10^{-3}$		2235
$(D^*(2010)^- \pi^+ \pi^+ \pi^-)$ nonresonant	$(0.0 \pm 2.5) \times 10^{-3}$		2235
$D^*(2010)^- \pi^+ \rho^0$	$(5.7 \pm 3.2) \times 10^{-3}$		2150
$D^*(2010)^- a_1(1260)^+$	(1.30 ± 0.27) %		2061
$\overline{D}_1(2420)^0 \pi^- \pi^+$, $\overline{D}_1^0 \to D^{*-} \pi^+$	$(1.47 \pm 0.35) \times 10^{-4}$		–
$D^*(2010)^- K^+ \pi^- \pi^+$	$(4.7 \pm 0.4) \times 10^{-4}$		2181
$D^*(2010)^- \pi^+ \pi^+ \pi^- \pi^0$	(1.76 ± 0.27) %		2218
$D^{*-} 3\pi^+ 2\pi^-$	$(4.7 \pm 0.9) \times 10^{-3}$		2195
$D^*(2010)^- \omega \pi^+$	$(2.46 \pm 0.18) \times 10^{-3}$	S=1.2	2148
$\overline{D}_1(2430)^0 \omega$, $\overline{D}_1^0 \to D^{*-} \pi^+$	$(2.7 {}^{+0.8}_{-0.4}) \times 10^{-4}$		1992
$D^{*-} \rho(1450)^+$, $\rho^+ \to \omega \pi^+$	$(1.07 {}^{+0.40}_{-0.34}) \times 10^{-3}$		–
$\overline{D}_1(2420)^0 \omega$, $\overline{D}_1^0 \to D^{*-} \pi^+$	$(7.0 \pm 2.2) \times 10^{-5}$		1995
$\overline{D}_2^*(2460)^0 \omega$, $\overline{D}_2^0 \to D^{*-} \pi^+$	$(4.0 \pm 1.4) \times 10^{-5}$		1975

$D^{*-} b_1(1235)^+$, $b_1^+ \to \omega\pi^+$		$< 7 \times 10^{-5}$	CL=90%	–
$\overline{D}^{**-}\pi^+$	[qqq]	$(1.9 \pm 0.9) \times 10^{-3}$		–
$D_1(2420)^-\pi^+$, $D_1^- \to D^-\pi^+\pi^-$		$(9.9 {}^{+2.0}_{-2.5}) \times 10^{-5}$		–
$D_1(2420)^-\pi^+$, $D_1^- \to D^{*-}\pi^+\pi^-$		$< 3.3 \times 10^{-5}$	CL=90%	–
$\overline{D}_2^*(2460)^-\pi^+$, $(D_2^*)^- \to D^0\pi^-$		$(2.38 \pm 0.16) \times 10^{-4}$		2062
$\overline{D}_0^*(2400)^-\pi^+$, $(D_0^*)^- \to D^0\pi^-$		$(7.6 \pm 0.8) \times 10^{-5}$		2090
$D_2^*(2460)^-\pi^+$, $(D_2^*)^- \to D^{*-}\pi^+\pi^-$		$< 2.4 \times 10^{-5}$	CL=90%	–
$\overline{D}_2^*(2460)^-\rho^+$		$< 4.9 \times 10^{-3}$	CL=90%	1974
$D^0\overline{D}^0$		$(1.4 \pm 0.7) \times 10^{-5}$		1868
$D^{*0}\overline{D}^0$		$< 2.9 \times 10^{-4}$	CL=90%	1794
D^-D^+		$(2.11 \pm 0.18) \times 10^{-4}$		1864
$D^\pm D^{*\mp}$ (CP-averaged)		$(6.1 \pm 0.6) \times 10^{-4}$		–
$D^-D_s^+$		$(7.2 \pm 0.8) \times 10^{-3}$		1812
$D^*(2010)^-D_s^+$		$(8.0 \pm 1.1) \times 10^{-3}$		1735
$D^-D_s^{*+}$		$(7.4 \pm 1.6) \times 10^{-3}$		1732
$D^*(2010)^-D_s^{*+}$		(1.77 ± 0.14) %		1649
$D_{s0}(2317)^-K^+$, $D_{s0}^- \to D_s^-\pi^0$		$(4.2 \pm 1.4) \times 10^{-5}$		2097
$D_{s0}(2317)^-\pi^+$, $D_{s0}^- \to D_s^-\pi^0$		$< 2.5 \times 10^{-5}$	CL=90%	2128
$D_{sJ}(2457)^-K^+$, $D_{sJ}^- \to D_s^-\pi^0$		$< 9.4 \times 10^{-6}$	CL=90%	–
$D_{sJ}(2457)^-\pi^+$, $D_{sJ}^- \to D_s^-\pi^0$		$< 4.0 \times 10^{-6}$	CL=90%	–
$D_s^-D_s^+$		$< 3.6 \times 10^{-5}$	CL=90%	1759
$D_s^{*-}D_s^+$		$< 1.3 \times 10^{-4}$	CL=90%	1674
$D_s^{*-}D_s^{*+}$		$< 2.4 \times 10^{-4}$	CL=90%	1583
$D_{s0}^*(2317)^+D^-$, $D_{s0}^{*+} \to D_s^+\pi^0$		$(1.06 \pm 0.16) \times 10^{-3}$	S=1.1	1602
$D_{s0}(2317)^+D^-$, $D_{s0}^+ \to D_s^{*+}\gamma$		$< 9.5 \times 10^{-4}$	CL=90%	–
$D_{s0}(2317)^+D^*(2010)^-$, $D_{s0}^+ \to D_s^+\pi^0$		$(1.5 \pm 0.6) \times 10^{-3}$		1509
$D_{sJ}(2457)^+D^-$		$(3.5 \pm 1.1) \times 10^{-3}$		–
$D_{sJ}(2457)^+D^-$, $D_{sJ}^+ \to D_s^+\gamma$		$(6.5 {}^{+1.7}_{-1.4}) \times 10^{-4}$		–
$D_{sJ}(2457)^+D^-$, $D_{sJ}^+ \to D_s^{*+}\gamma$		$< 6.0 \times 10^{-4}$	CL=90%	–
$D_{sJ}(2457)^+D^-$, $D_{sJ}^+ \to D_s^+\pi^+\pi^-$		$< 2.0 \times 10^{-4}$	CL=90%	–
$D_{sJ}(2457)^+D^-$, $D_{sJ}^+ \to D_s^+\pi^0$		$< 3.6 \times 10^{-4}$	CL=90%	–
$D^*(2010)^-D_{sJ}(2457)^+$		$(9.3 \pm 2.2) \times 10^{-3}$		–
$D_{sJ}(2457)^+D^*(2010)$, $D_{sJ}^+ \to D_s^+\gamma$		$(2.3 {}^{+0.9}_{-0.7}) \times 10^{-3}$		–
$D^-D_{s1}(2536)^+$, $D_{s1}^+ \to D^{*0}K^+ + D^{*+}K^0$		$(2.8 \pm 0.7) \times 10^{-4}$		1444
$D^-D_{s1}(2536)^+$, $D_{s1}^+ \to D^{*0}K^+$		$(1.7 \pm 0.6) \times 10^{-4}$		1444
$D^-D_{s1}(2536)^+$, $D_{s1}^+ \to D^{*+}K^0$		$(2.6 \pm 1.1) \times 10^{-4}$		1444
$D^*(2010)^-D_{s1}(2536)^+$, $D_{s1}^+ \to D^{*0}K^+ + D^{*+}K^0$		$(5.0 \pm 1.4) \times 10^{-4}$		1336
$D^*(2010)^-D_{s1}(2536)^+$, $D_{s1}^+ \to D^{*0}K^+$		$(3.3 \pm 1.1) \times 10^{-4}$		1336

$D^{*-} D_{s1}(2536)^+$, $D^+_{s1} \to D^{*+} K^0$	$(5.0 \pm 1.7) \times 10^{-4}$		1336
$D^- D_{sJ}(2573)^+$, $D^+_{sJ} \to D^0 K^+$	$(3.4 \pm 1.8) \times 10^{-5}$		1414
$D^*(2010)^- D_{sJ}(2573)^+$, $D^+_{sJ} \to D^0 K^+$	$< 2 \times 10^{-4}$	CL=90%	1304
$D^- D_{sJ}(2700)^+$, $D^+_{sJ} \to D^0 K^+$	$(7.1 \pm 1.2) \times 10^{-4}$		–
$D^+ \pi^-$	$(7.4 \pm 1.3) \times 10^{-7}$		2306
$D^+_s \pi^-$	$(2.16 \pm 0.26) \times 10^{-5}$		2270
$D^{*+}_s \pi^-$	$(2.1 \pm 0.4) \times 10^{-5}$	S=1.4	2215
$D^+_s \rho^-$	$< 2.4 \times 10^{-5}$	CL=90%	2197
$D^{*+}_s \rho^-$	$(4.1 \pm 1.3) \times 10^{-5}$		2138
$D^+_s a^-_0$	$< 1.9 \times 10^{-5}$	CL=90%	–
$D^{*+}_s a^-_0$	$< 3.6 \times 10^{-5}$	CL=90%	–
$D^+_s a_1(1260)^-$	$< 2.1 \times 10^{-3}$	CL=90%	2080
$D^{*+}_s a_1(1260)^-$	$< 1.7 \times 10^{-3}$	CL=90%	2015
$D^+_s a^-_2$	$< 1.9 \times 10^{-4}$	CL=90%	–
$D^{*+}_s a^-_2$	$< 2.0 \times 10^{-4}$	CL=90%	–
$D^-_s K^+$	$(2.7 \pm 0.5) \times 10^{-5}$	S=2.7	2242
$D^{*-}_s K^+$	$(2.19 \pm 0.30) \times 10^{-5}$		2185
$D^-_s K^*(892)^+$	$(3.5 \pm 1.0) \times 10^{-5}$		2172
$D^{*-}_s K^*(892)^+$	$(3.2 {}^{+1.5}_{-1.3}) \times 10^{-5}$		2112
$D^-_s \pi^+ K^0$	$(9.7 \pm 1.4) \times 10^{-5}$		2222
$D^{*-}_s \pi^+ K^0$	$< 1.10 \times 10^{-4}$	CL=90%	2164
$D^-_s K^+ \pi^+ \pi^-$	$(1.7 \pm 0.5) \times 10^{-4}$		2198
$D^-_s \pi^+ K^*(892)^0$	$< 3.0 \times 10^{-3}$	CL=90%	2138
$D^{*-}_s \pi^+ K^*(892)^0$	$< 1.6 \times 10^{-3}$	CL=90%	2076
$\overline{D}^0 K^0$	$(5.2 \pm 0.7) \times 10^{-5}$		2280
$\overline{D}^0 K^+ \pi^-$	$(8.8 \pm 1.7) \times 10^{-5}$		2261
$\overline{D}^0 K^*(892)^0$	$(4.5 \pm 0.6) \times 10^{-5}$		2213
$\overline{D}^0 K^*(1410)^0$	$< 6.7 \times 10^{-5}$	CL=90%	2062
$\overline{D}^0 K^*_0(1430)^0$	$(7 \pm 7) \times 10^{-6}$		2058
$\overline{D}^0 K^*_2(1430)^0$	$(2.1 \pm 0.9) \times 10^{-5}$		2057
$D^*_0(2300)^- K^+$, $D^{*-}_0 \to \overline{D}^0 \pi^-$	$(1.9 \pm 0.9) \times 10^{-5}$		–
$D^*_2(2460)^- K^+$, $D^{*-}_2 \to \overline{D}^0 \pi^-$	$(2.03 \pm 0.35) \times 10^{-5}$		2029
$D^*_3(2760)^- K^+$, $D^{*-}_3 \to \overline{D}^0 \pi^-$	$< 1.0 \times 10^{-6}$	CL=90%	–
$\overline{D}^0 K^+ \pi^-$ nonresonant	$< 3.7 \times 10^{-5}$	CL=90%	2261
$[K^+ K^-]_D K^*(892)^0$	$(4.2 \pm 0.7) \times 10^{-5}$		–
$[\pi^+ \pi^-]_D K^*(892)^0$	$(6.0 \pm 1.1) \times 10^{-5}$		–
$[\pi^+ \pi^- \pi^+ \pi^-]_D K^{*0}$	$(4.6 \pm 0.9) \times 10^{-5}$		–
$\overline{D}^0 \pi^0$	$(2.63 \pm 0.14) \times 10^{-4}$		2308
$\overline{D}^0 \rho^0$	$(3.21 \pm 0.21) \times 10^{-4}$		2237
$\overline{D}^0 f_2$	$(1.56 \pm 0.21) \times 10^{-4}$		–
$\overline{D}^0 \eta$	$(2.36 \pm 0.32) \times 10^{-4}$	S=2.5	2274
$\overline{D}^0 \eta'$	$(1.38 \pm 0.16) \times 10^{-4}$	S=1.3	2198
$\overline{D}^0 \omega$	$(2.54 \pm 0.16) \times 10^{-4}$		2235
$D^0 \phi$	$< 2.3 \times 10^{-6}$	CL=95%	2183
$D^0 K^+ \pi^-$	$(5.3 \pm 3.2) \times 10^{-6}$		2261

$D^0 K^*(892)^0$	$(2.2 ^{+0.9}_{-1.0}) \times 10^{-6}$		2213
$\overline{D}^{*0} \gamma$	$< 2.5 \times 10^{-5}$	CL=90%	2258
$\overline{D}^*(2007)^0 \pi^0$	$(2.2 \pm 0.6) \times 10^{-4}$	S=2.6	2256
$\overline{D}^*(2007)^0 \rho^0$	$< 5.1 \times 10^{-4}$	CL=90%	2182
$\overline{D}^*(2007)^0 \eta$	$(2.3 \pm 0.6) \times 10^{-4}$	S=2.8	2220
$\overline{D}^*(2007)^0 \eta'$	$(1.40 \pm 0.22) \times 10^{-4}$		2141
$\overline{D}^*(2007)^0 \pi^+ \pi^-$	$(6.2 \pm 2.2) \times 10^{-4}$		2249
$\overline{D}^*(2007)^0 K^0$	$(3.6 \pm 1.2) \times 10^{-5}$		2227
$\overline{D}^*(2007)^0 K^*(892)^0$	$< 6.9 \times 10^{-5}$	CL=90%	2157
$D^*(2007)^0 K^*(892)^0$	$< 4.0 \times 10^{-5}$	CL=90%	2157
$D^*(2007)^0 \pi^+ \pi^+ \pi^- \pi^-$	$(2.7 \pm 0.5) \times 10^{-3}$		2219
$D^*(2010)^+ D^*(2010)^-$	$(8.0 \pm 0.6) \times 10^{-4}$		1711
$\overline{D}^*(2007)^0 \omega$	$(3.6 \pm 1.1) \times 10^{-4}$	S=3.1	2180
$D^*(2010)^+ D^-$	$(6.1 \pm 1.5) \times 10^{-4}$	S=1.6	1790
$D^*(2007)^0 \overline{D}^*(2007)^0$	$< 9 \times 10^{-5}$	CL=90%	1715
$D^- D^0 K^+$	$(1.07 \pm 0.11) \times 10^{-3}$		1574
$D^- D^*(2007)^0 K^+$	$(3.5 \pm 0.4) \times 10^{-3}$		1478
$D^*(2010)^- D^0 K^+$	$(2.47 \pm 0.21) \times 10^{-3}$		1479
$D^*(2010)^- D^*(2007)^0 K^+$	(1.06 ± 0.09) %		1366
$D^- D^+ K^0$	$(7.5 \pm 1.7) \times 10^{-4}$		1568
$D^*(2010)^- D^+ K^0 + D^- D^*(2010)^+ K^0$	$(6.4 \pm 0.5) \times 10^{-3}$		1473
$D^*(2010)^- D^*(2010)^+ K^0$	$(8.1 \pm 0.7) \times 10^{-3}$		1360
$D^{*-} D_{s1}(2536)^+$, $D_{s1}^+ \to D^{*+} K^0$	$(8.0 \pm 2.4) \times 10^{-4}$		1336
$\overline{D}^0 D^0 K^0$	$(2.7 \pm 1.1) \times 10^{-4}$		1574
$\overline{D}^0 D^*(2007)^0 K^0 + \overline{D}^*(2007)^0 D^0 K^0$	$(1.1 \pm 0.5) \times 10^{-3}$		1478
$\overline{D}^*(2007)^0 D^*(2007)^0 K^0$	$(2.4 \pm 0.9) \times 10^{-3}$		1365
$(\overline{D}+\overline{D}^*)(D+D^*) K$	(3.68 ± 0.26) %		–
Charmonium modes			
$\eta_c K^0$	$(8.0 \pm 1.1) \times 10^{-4}$		1751
$\eta_c(1S) K^+ \pi^-$	$(6.0 \pm 0.7) \times 10^{-4}$		1722
$\eta_c(1S) K^+ \pi^-$ (NR)	$(6.2 \pm 1.3) \times 10^{-5}$		–
$X(4100)^- K^+$, $X^- \to \eta_c \pi^-$	$(2.0 \pm 1.0) \times 10^{-5}$		–
$\eta_c(1S) K^*(1410)^0$	$(1.9 \pm 1.5) \times 10^{-4}$		1395
$\eta_c(1S) K_0^*(1430)^0$	$(1.6 \pm 0.4) \times 10^{-4}$		1387
$\eta_c(1S) K_2^*(1430)^0$	$(4.9 ^{+2.2}_{-2.7}) \times 10^{-5}$		1386
$\eta_c(1S) K^*(1680)^0$	$(3 \pm 4) \times 10^{-5}$		1166
$\eta_c(1S) K_0^*(1950)^0$	$(4.4 ^{+2.9}_{-4.0}) \times 10^{-5}$		–
$\eta_c K^*(892)^0$	$(5.2 ^{+0.7}_{-0.8}) \times 10^{-4}$	S=1.5	1646
$\eta_c(2S) K_S^0$, $\eta_c \to p \overline{p} \pi^+ \pi^-$	$(4.2 ^{+1.4}_{-1.2}) \times 10^{-7}$		–
$\eta_c(2S) K^{*0}$	$< 3.9 \times 10^{-4}$	CL=90%	1159
$h_c(1P) K_S^0$	$< 1.4 \times 10^{-5}$		1401
$h_c(1P) K^{*0}$	$< 4 \times 10^{-4}$	CL=90%	1253
$J/\psi(1S) K^0$	$(8.68 \pm 0.30) \times 10^{-4}$		1683
$J/\psi(1S) K^+ \pi^-$	$(1.15 \pm 0.05) \times 10^{-3}$		1652
$J/\psi(1S) K^*(892)^0$	$(1.27 \pm 0.05) \times 10^{-3}$		1571
$J/\psi(1S) \eta K_S^0$	$(5.4 \pm 0.9) \times 10^{-5}$		1508
$J/\psi(1S) \eta' K_S^0$	$< 2.5 \times 10^{-5}$	CL=90%	1271
$J/\psi(1S) \phi K^0$	$(4.9 \pm 1.0) \times 10^{-5}$	S=1.3	1224

$J/\psi(1S)\omega K^0$	$(2.3 \pm 0.4) \times 10^{-4}$		1386
$\chi_{c1}(3872) K^0$, $\chi_{c1} \to J/\psi\omega$	$(6.0 \pm 3.2) \times 10^{-6}$		1140
$X(3915)$, $X \to J/\psi\omega$	$(2.1 \pm 0.9) \times 10^{-5}$		1102
$J/\psi(1S) K(1270)^0$	$(1.3 \pm 0.5) \times 10^{-3}$		1402
$J/\psi(1S)\pi^0$	$(1.66 \pm 0.10) \times 10^{-5}$		1728
$J/\psi(1S)\eta$	$(1.08 \pm 0.23) \times 10^{-5}$	S=1.5	1673
$J/\psi(1S)\pi^+\pi^-$	$(3.94 \pm 0.17) \times 10^{-5}$		1716
$J/\psi(1S)\pi^+\pi^-$ nonresonant	$< 1.2 \times 10^{-5}$	CL=90%	1716
$J/\psi(1S) f_0(500)$, $f_0 \to \pi\pi$	$(8.8 {+1.2 \atop -1.6}) \times 10^{-6}$		–
$J/\psi(1S) f_2$	$(3.3 \pm 0.5) \times 10^{-6}$	S=1.5	–
$J/\psi(1S)\rho^0$	$(2.55 {+0.18 \atop -0.16}) \times 10^{-5}$		1612
$J/\psi(1S) f_0(980)$, $f_0 \to \pi^+\pi^-$	$< 1.1 \times 10^{-6}$	CL=90%	–
$J/\psi(1S)\rho(1450)^0$, $\rho^0 \to \pi\pi$	$(2.9 {+1.6 \atop -0.7}) \times 10^{-6}$		–
$J/\psi\rho(1700)^0$, $\rho^0 \to \pi^+\pi^-$	$(2.0 \pm 1.3) \times 10^{-6}$		–
$J/\psi(1S)\omega$	$(1.8 {+0.7 \atop -0.5}) \times 10^{-5}$		1609
$J/\psi(1S) K^+ K^-$	$(2.50 \pm 0.35) \times 10^{-6}$		1534
$J/\psi(1S) a_0(980)$, $a_0 \to K^+ K^-$	$(4.7 \pm 3.4) \times 10^{-7}$		–
$J/\psi(1S)\phi$	$< 1.9 \times 10^{-7}$	CL=90%	1520
$J/\psi(1S)\eta'(958)$	$(7.6 \pm 2.4) \times 10^{-6}$		1546
$J/\psi(1S) K^0\pi^+\pi^-$	$(4.3 \pm 0.4) \times 10^{-4}$		1611
$J/\psi(1S) K^0 K^-\pi^+$ + c.c.	$< 2.1 \times 10^{-5}$	CL=90%	1467
$J/\psi(1S) K^0 K^+ K^-$	$(2.5 \pm 0.7) \times 10^{-5}$	S=1.8	1249
$J/\psi(1S) K^0\rho^0$	$(5.4 \pm 3.0) \times 10^{-4}$		1390
$J/\psi(1S) K^*(892)^+\pi^-$	$(8 \pm 4) \times 10^{-4}$		1515
$J/\psi(1S)\pi^+\pi^-\pi^+\pi^-$	$(1.42 \pm 0.12) \times 10^{-5}$		1670
$J/\psi(1S) f_1(1285)$	$(8.4 \pm 2.1) \times 10^{-6}$		1385
$J/\psi(1S) K^*(892)^0\pi^+\pi^-$	$(6.6 \pm 2.2) \times 10^{-4}$		1447
$\chi_{c1}(3872)^- K^+$	$< 5 \times 10^{-4}$	CL=90%	–
$\chi_{c1}(3872)^- K^+$, $\chi_{c1}(3872)^- \to J/\psi(1S)\pi^-\pi^0$ [rrr]	$< 4.2 \times 10^{-6}$	CL=90%	–
$\chi_{c1}(3872) K^0$, $\chi_{c1} \to J/\psi\pi^+\pi^-$	$(4.3 \pm 1.3) \times 10^{-6}$		1140
$\chi_{c1}(3872) K^0$, $\chi_{c1} \to J/\psi\gamma$	$< 2.4 \times 10^{-6}$	CL=90%	1140
$\chi_{c1}(3872) K^*(892)^0$, $\chi_{c1} \to J/\psi\gamma$	$< 2.8 \times 10^{-6}$	CL=90%	940
$\chi_{c1}(3872) K^0$, $\chi_{c1} \to \psi(2S)\gamma$	$< 6.62 \times 10^{-6}$	CL=90%	1140
$\chi_{c1}(3872) K^*(892)^0$, $\chi_{c1} \to \psi(2S)\gamma$	$< 4.4 \times 10^{-6}$	CL=90%	940
$\chi_{c1}(3872) K^0$, $\chi_{c1} \to D^0\overline{D}^0\pi^0$	$(1.7 \pm 0.8) \times 10^{-4}$		1140
$\chi_{c1}(3872) K^0$, $\chi_{c1} \to \overline{D}^{*0} D^0$	$(1.2 \pm 0.4) \times 10^{-4}$		1140
$\chi_{c1}(3872) K^+\pi^-$, $\chi_{c1} \to J/\psi\pi^+\pi^-$	$(7.9 \pm 1.4) \times 10^{-6}$		–
$\chi_{c1}(3872) K^*(892)^0$, $\chi_{c1} \to J/\psi\pi^+\pi^-$	$(4.0 \pm 1.5) \times 10^{-6}$		–
$\chi_{c1}(3872)\gamma$, $\chi_{c1} \to J/\psi\pi^+\pi^-$	$< 5.1 \times 10^{-7}$	CL=90%	–
$Z_c(4430)^\pm K^\mp$, $Z_c^\pm \to \psi(2S)\pi^\pm$	$(6.0 {+3.0 \atop -2.4}) \times 10^{-5}$		583
$Z_c(4430)^\pm K^\mp$, $Z_c^\pm \to J/\psi\pi^\pm$	$(5.4 {+4.0 \atop -1.2}) \times 10^{-6}$		583
$Z_c(3900)^\pm K^\mp$, $Z_c^\pm \to J/\psi\pi^\pm$	$< 9 \times 10^{-7}$		–
$Z_c(4200)^\pm K^\mp$, $X^\pm \to J/\psi\pi^\pm$	$(2.2 {+1.3 \atop -0.8}) \times 10^{-5}$		–

$J/\psi(1S)\, p\overline{p}$	$(4.5 \pm 0.6) \times 10^{-7}$		862
$J/\psi(1S)\, \gamma$	$< 1.5 \times 10^{-6}$	CL=90%	1732
$J/\psi(1S)\, \overline{D}^0$	$< 1.3 \times 10^{-5}$	CL=90%	877
$\psi(2S)\, \pi^0$	$(1.17 \pm 0.19) \times 10^{-5}$		1348
$\psi(2S)\, K^0$	$(5.8 \pm 0.5) \times 10^{-4}$		1283
$\psi(3770)\, K^0,\ \psi \rightarrow \overline{D}^0\, D^0$	$< 1.23 \times 10^{-4}$	CL=90%	1217
$\psi(3770)\, K^0,\ \psi \rightarrow D^-\, D^+$	$< 1.88 \times 10^{-4}$	CL=90%	1217
$\psi(2S)\, \pi^+ \pi^-$	$(2.21 \pm 0.35) \times 10^{-5}$		1331
$\psi(2S)\, K^+ \pi^-$	$(5.8 \pm 0.4) \times 10^{-4}$		1239
$\psi(2S)\, K^*(892)^0$	$(5.9 \pm 0.4) \times 10^{-4}$		1116
$\chi_{c0}\, K^0$	$(1.11^{+0.24}_{-0.21}) \times 10^{-6}$		1477
$\chi_{c0}\, K^*(892)^0$	$(1.7 \pm 0.4) \times 10^{-4}$		1342
$\chi_{c1}\, \pi^0$	$(1.12 \pm 0.28) \times 10^{-5}$		1468
$\chi_{c1}\, K^0$	$(3.95 \pm 0.27) \times 10^{-4}$		1411
$\chi_{c1}\, \pi^- K^+$	$(4.97 \pm 0.30) \times 10^{-4}$		1371
$\chi_{c1}\, K^*(892)^0$	$(2.38 \pm 0.19) \times 10^{-4}$	S=1.2	1265
$X(4051)^- K^+,\ X^- \rightarrow \chi_{c1}\, \pi^-$	$(3.0 ^{+4.0}_{-1.8}) \times 10^{-5}$		–
$X(4248)^- K^+,\ X^- \rightarrow \chi_{c1}\, \pi^-$	$(4.0 ^{+20.0}_{-1.0}) \times 10^{-5}$		–
$\chi_{c1}\, \pi^+ \pi^- K^0$	$(3.2 \pm 0.5) \times 10^{-4}$		1318
$\chi_{c1}\, \pi^- \pi^0 K^+$	$(3.5 \pm 0.6) \times 10^{-4}$		1321
$\chi_{c2}\, K^0$	$< 1.5 \times 10^{-5}$	CL=90%	1379
$\chi_{c2}\, K^*(892)^0$	$(4.9 \pm 1.2) \times 10^{-5}$	S=1.1	1228
$\chi_{c2}\, \pi^- K^+$	$(7.2 \pm 1.0) \times 10^{-5}$		1338
$\chi_{c2}\, \pi^+ \pi^- K^0$	$< 1.70 \times 10^{-4}$	CL=90%	1282
$\chi_{c2}\, \pi^- \pi^0 K^+$	$< 7.4 \times 10^{-5}$	CL=90%	1286
$\psi(4660)\, K^0,\ \psi \rightarrow \Lambda_c^+ \Lambda_c^-$	$< 2.3 \times 10^{-4}$	CL=90%	–
$\psi(4260)^0\, K^0,\ \psi^0 \rightarrow J/\psi \pi^+ \pi^-$	$< 1.7 \times 10^{-5}$	CL=90%	–

K or K^* modes

$K^+ \pi^-$	$(1.96 \pm 0.05) \times 10^{-5}$		2615
$K^0 \pi^0$	$(9.9 \pm 0.5) \times 10^{-6}$		2615
$\eta' K^0$	$(6.6 \pm 0.4) \times 10^{-5}$	S=1.4	2528
$\eta' K^*(892)^0$	$(2.8 \pm 0.6) \times 10^{-6}$		2472
$\eta' K_0^*(1430)^0$	$(6.3 \pm 1.6) \times 10^{-6}$		2346
$\eta' K_2^*(1430)^0$	$(1.37 \pm 0.32) \times 10^{-5}$		2346
ηK^0	$(1.23^{+0.27}_{-0.24}) \times 10^{-6}$		2587
$\eta K^*(892)^0$	$(1.59 \pm 0.10) \times 10^{-5}$		2534
$\eta K_0^*(1430)^0$	$(1.10 \pm 0.22) \times 10^{-5}$		2415
$\eta K_2^*(1430)^0$	$(9.6 \pm 2.1) \times 10^{-6}$		2414
ωK^0	$(4.8 \pm 0.4) \times 10^{-6}$		2557
$a_0(980)^0 K^0,\ a_0^0 \rightarrow \eta \pi^0$	$< 7.8 \times 10^{-6}$	CL=90%	–
$b_1^0 K^0,\ b_1^0 \rightarrow \omega \pi^0$	$< 7.8 \times 10^{-6}$	CL=90%	–
$a_0(980)^\pm K^\mp,\ a_0^\pm \rightarrow \eta \pi^\pm$	$< 1.9 \times 10^{-6}$	CL=90%	–
$b_1^- K^+,\ b_1^- \rightarrow \omega \pi^-$	$(7.4 \pm 1.4) \times 10^{-6}$		–
$b_1^0 K^{*0},\ b_1^0 \rightarrow \omega \pi^0$	$< 8.0 \times 10^{-6}$	CL=90%	–
$b_1^- K^{*+},\ b_1^- \rightarrow \omega \pi^-$	$< 5.0 \times 10^{-6}$	CL=90%	–
$a_0(1450)^\pm K^\mp,\ a_0^\pm \rightarrow \eta \pi^\pm$	$< 3.1 \times 10^{-6}$	CL=90%	–
$K_S^0 X^0$ (Familon)	$< 5.3 \times 10^{-5}$	CL=90%	–
$\omega K^*(892)^0$	$(2.0 \pm 0.5) \times 10^{-6}$		2503
$\omega (K\pi)_0^{*0}$	$(1.84 \pm 0.25) \times 10^{-5}$		–
$\omega K_0^*(1430)^0$	$(1.60 \pm 0.34) \times 10^{-5}$		2380
$\omega K_2^*(1430)^0$	$(1.01 \pm 0.23) \times 10^{-5}$		2380

$\omega K^+ \pi^-$ nonresonant		$(5.1 \pm 1.0) \times 10^{-6}$		2542
$K^+ \pi^- \pi^0$		$(3.78 \pm 0.32) \times 10^{-5}$		2609
$K^+ \rho^-$		$(7.0 \pm 0.9) \times 10^{-6}$		2559
$K^+ \rho(1450)^-$		$(2.4 \pm 1.2) \times 10^{-6}$		–
$K^+ \rho(1700)^-$		$(6 \pm 7) \times 10^{-7}$		–
$(K^+ \pi^- \pi^0)$ nonresonant		$(2.8 \pm 0.6) \times 10^{-6}$		2609
$(K\pi)_0^{*+} \pi^-$, $(K\pi)_0^{*+} \to K^+ \pi^0$		$(3.4 \pm 0.5) \times 10^{-5}$		–
$(K\pi)_0^{*0} \pi^0$, $(K\pi)_0^{*0} \to K^+ \pi^-$		$(8.6 \pm 1.7) \times 10^{-6}$		–
$K_2^*(1430)^0 \pi^0$		$< 4.0 \times 10^{-6}$	CL=90%	2445
$K^*(1680)^0 \pi^0$		$< 7.5 \times 10^{-6}$	CL=90%	2358
$K_x^{*0} \pi^0$	[uuu]	$(6.1 \pm 1.6) \times 10^{-6}$		–
$K^0 \pi^+ \pi^-$		$(4.97 \pm 0.18) \times 10^{-5}$		2609
$K^0 \pi^+ \pi^-$ nonresonant		$(1.39^{+0.26}_{-0.18}) \times 10^{-5}$	S=1.6	2609
$K^0 \rho^0$		$(3.4 \pm 1.1) \times 10^{-6}$	S=2.3	2558
$K^*(892)^+ \pi^-$		$(7.5 \pm 0.4) \times 10^{-6}$		2563
$K_0^*(1430)^+ \pi^-$		$(3.3 \pm 0.7) \times 10^{-5}$	S=2.0	–
$K_x^{*+} \pi^-$	[uuu]	$(5.1 \pm 1.6) \times 10^{-6}$		–
$K^*(1410)^+ \pi^-$, $K^{*+} \to K^0 \pi^+$		$< 3.8 \times 10^{-6}$	CL=90%	–
$(K\pi)_0^{*+} \pi^-$, $(K\pi)_0^{*+} \to K^0 \pi^+$		$(1.62 \pm 0.13) \times 10^{-5}$		–
$f_0(980) K^0$, $f_0 \to \pi^+ \pi^-$		$(8.1 \pm 0.8) \times 10^{-6}$	S=1.3	2522
$K^0 f_0(500)$		$(1.6^{+2.5}_{-1.6}) \times 10^{-7}$		–
$K^0 f_0(1500)$		$(1.3 \pm 0.8) \times 10^{-6}$		2397
$f_2(1270) K^0$		$(2.7^{+1.3}_{-1.2}) \times 10^{-6}$		2459
$f_x(1300) K0, f_x \to \pi^+ \pi^-$		$(1.8 \pm 0.7) \times 10^{-6}$		–
$K^*(892)^0 \pi^0$		$(3.3 \pm 0.6) \times 10^{-6}$		2563
$K_2^*(1430)^+ \pi^-$		$(3.65 \pm 0.34) \times 10^{-6}$		2445
$K^*(1680)^+ \pi^-$		$(1.41 \pm 0.10) \times 10^{-5}$		2358
$K^+ \pi^- \pi^+ \pi^-$	[vvv]	$< 2.3 \times 10^{-4}$	CL=90%	2600
$\rho^0 K^+ \pi^-$		$(2.8 \pm 0.7) \times 10^{-6}$		2543
$f_0(980) K^+ \pi^-$, $f_0 \to \pi\pi$		$(1.4^{+0.5}_{-0.6}) \times 10^{-6}$		2506
$K^+ \pi^- \pi^+ \pi^-$ nonresonant		$< 2.1 \times 10^{-6}$	CL=90%	2600
$K^*(892)^0 \pi^+ \pi^-$		$(5.5 \pm 0.5) \times 10^{-5}$		2557
$K^*(892)^0 \rho^0$		$(3.9 \pm 1.3) \times 10^{-6}$	S=1.9	2504
$K^*(892)^0 f_0(980)$, $f_0 \to \pi\pi$		$(3.9^{+2.1}_{-1.8}) \times 10^{-6}$	S=3.9	2466
$K_1(1270)^+ \pi^-$		$< 3.0 \times 10^{-5}$	CL=90%	2489
$K_1(1400)^+ \pi^-$		$< 2.7 \times 10^{-5}$	CL=90%	2451
$a_1(1260)^- K^+$	[vvv]	$(1.6 \pm 0.4) \times 10^{-5}$		2471
$K^*(892)^+ \rho^-$		$(1.03 \pm 0.26) \times 10^{-5}$		2504
$K_0^*(1430)^+ \rho^-$		$(2.8 \pm 1.2) \times 10^{-5}$		–
$K_1(1400)^0 \rho^0$		$< 3.0 \times 10^{-3}$	CL=90%	2388
$K_0^*(1430)^0 \rho^0$		$(2.7 \pm 0.6) \times 10^{-5}$		2381
$K_0^*(1430)^0 f_0(980)$, $f_0 \to \pi\pi$		$(2.7 \pm 0.9) \times 10^{-6}$		–
$K_2^*(1430)^0 f_0(980)$, $f_0 \to \pi\pi$		$(8.6 \pm 2.0) \times 10^{-6}$		–
$K^+ K^-$		$(7.8 \pm 1.5) \times 10^{-8}$		2593
$K^0 \overline{K}^0$		$(1.21 \pm 0.16) \times 10^{-6}$		2593
$K^0 K^- \pi^+$		$(6.7 \pm 0.5) \times 10^{-6}$		2578
$K^*(892)^{\pm} K^{\mp}$		$< 4 \times 10^{-7}$	CL=90%	2540
$\overline{K}^{*0} K^0 + K^{*0} \overline{K}^0$		$< 9.6 \times 10^{-7}$	CL=90%	–
$K^+ K^- \pi^0$		$(2.2 \pm 0.6) \times 10^{-6}$		2579

$K^0_S K^0_S \pi^0$	$< 9 \times 10^{-7}$	CL=90%	2578
$K^0_S K^0_S \eta$	$< 1.0 \times 10^{-6}$	CL=90%	2515
$K^0_S K^0_S \eta'$	$< 2.0 \times 10^{-6}$	CL=90%	2453
$K^0 K^+ K^-$	$(2.68 \pm 0.11) \times 10^{-5}$		2522
$K^0 \phi$	$(7.3 \pm 0.7) \times 10^{-6}$		2516
$f_0(980) K^0$, $f_0 \to K^+ K^-$	$(7.0 {}^{+3.5}_{-3.0}) \times 10^{-6}$		–
$f_0(1500) K^0$	$(1.3 {}^{+0.7}_{-0.5}) \times 10^{-5}$		2397
$f'_2(1525)^0 K^0$	$(3 {}^{+5}_{-4}) \times 10^{-7}$		–
$f_0(1710) K^0$, $f_0 \to K^+ K^-$	$(4.4 \pm 0.9) \times 10^{-6}$		–
$K^0 K^+ K^-$ nonresonant	$(3.3 \pm 1.0) \times 10^{-5}$		2522
$K^0_S K^0_S K^0_S$	$(6.0 \pm 0.5) \times 10^{-6}$	S=1.1	2521
$f_0(980) K^0$, $f_0 \to K^0_S K^0_S$	$(2.7 \pm 1.8) \times 10^{-6}$		–
$f_0(1710) K^0$, $f_0 \to K^0_S K^0_S$	$(5.0 {}^{+5.0}_{-2.6}) \times 10^{-7}$		–
$f_2(2010) K^0$, $f_2 \to K^0_S K^0_S$	$(5 \pm 6) \times 10^{-7}$		–
$K^0_S K^0_S K^0_S$ nonresonant	$(1.33 \pm 0.31) \times 10^{-5}$		2521
$K^0_S K^0_S K^0_L$	$< 1.6 \times 10^{-5}$	CL=90%	2521
$K^*(892)^0 K^+ K^-$	$(2.75 \pm 0.26) \times 10^{-5}$		2467
$K^*(892)^0 \phi$	$(1.00 \pm 0.05) \times 10^{-5}$		2460
$K^+ K^- \pi^+ \pi^-$ nonresonant	$< 7.17 \times 10^{-5}$	CL=90%	2559
$K^*(892)^0 K^- \pi^+$	$(4.5 \pm 1.3) \times 10^{-6}$		2524
$K^*(892)^0 \overline{K}^*(892)^0$	$(8.3 \pm 2.4) \times 10^{-7}$	S=1.5	2485
$K^+ K^+ \pi^- \pi^-$ nonresonant	$< 6.0 \times 10^{-6}$	CL=90%	2559
$K^*(892)^0 K^+ \pi^-$	$< 2.2 \times 10^{-6}$	CL=90%	2524
$K^*(892)^0 K^*(892)^0$	$< 2 \times 10^{-7}$	CL=90%	2485
$K^*(892)^+ K^*(892)^-$	$< 2.0 \times 10^{-6}$	CL=90%	2485
$K_1(1400)^0 \phi$	$< 5.0 \times 10^{-3}$	CL=90%	2339
$\phi (K\pi)^{*0}_0$	$(4.3 \pm 0.4) \times 10^{-6}$		–
$\phi (K\pi)^{*0}_0$ $(1.60 < m_{K\pi} < 2.15)$ [xxx]	$< 1.7 \times 10^{-6}$	CL=90%	–
$K^*_0(1430)^0 K^- \pi^+$	$< 3.18 \times 10^{-5}$	CL=90%	2403
$K^*_0(1430)^0 \overline{K}^*(892)^0$	$< 3.3 \times 10^{-6}$	CL=90%	2360
$K^*_0(1430)^0 \overline{K}^*_0(1430)^0$	$< 8.4 \times 10^{-6}$	CL=90%	2222
$K^*_0(1430)^0 \phi$	$(3.9 \pm 0.8) \times 10^{-6}$		2333
$K^*_0(1430)^0 K^*(892)^0$	$< 1.7 \times 10^{-6}$	CL=90%	2360
$K^*_0(1430)^0 K^*_0(1430)^0$	$< 4.7 \times 10^{-6}$	CL=90%	2222
$K^*(1680)^0 \phi$	$< 3.5 \times 10^{-6}$	CL=90%	2238
$K^*(1780)^0 \phi$	$< 2.7 \times 10^{-6}$	CL=90%	–
$K^*(2045)^0 \phi$	$< 1.53 \times 10^{-5}$	CL=90%	–
$K^*_2(1430)^0 \rho^0$	$< 1.1 \times 10^{-3}$	CL=90%	2381
$K^*_2(1430)^0 \phi$	$(6.8 \pm 0.9) \times 10^{-6}$	S=1.2	2332
$K^0 \phi \phi$	$(4.5 \pm 0.9) \times 10^{-6}$		2305
$\eta' \eta' K^0$	$< 3.1 \times 10^{-5}$	CL=90%	2337
$\eta K^0 \gamma$	$(7.6 \pm 1.8) \times 10^{-6}$		2587
$\eta' K^0 \gamma$	$< 6.4 \times 10^{-6}$	CL=90%	2528
$K^0 \phi \gamma$	$(2.7 \pm 0.7) \times 10^{-6}$		2516
$K^+ \pi^- \gamma$	$(4.6 \pm 1.4) \times 10^{-6}$		2615
$K^*(892)^0 \gamma$	$(4.18 \pm 0.25) \times 10^{-5}$	S=2.1	2565
$K^*(1410) \gamma$	$< 1.3 \times 10^{-4}$	CL=90%	2451
$K^+ \pi^- \gamma$ nonresonant	$< 2.6 \times 10^{-6}$	CL=90%	2615
$K^*(892)^0 X(214)$, $X \to \mu^+ \mu^-$ [yyy]	$< 2.26 \times 10^{-8}$	CL=90%	–
$K^0 \pi^+ \pi^- \gamma$	$(1.99 \pm 0.18) \times 10^{-5}$		2609
$K^+ \pi^- \pi^0 \gamma$	$(4.1 \pm 0.4) \times 10^{-5}$		2609

$K_1(1270)^0\gamma$		$< 5.8 \times 10^{-5}$	CL=90%	2491
$K_1(1400)^0\gamma$		$< 1.2 \times 10^{-5}$	CL=90%	2454
$K_2^*(1430)^0\gamma$		$(1.24\pm 0.24) \times 10^{-5}$		2447
$K^*(1680)^0\gamma$		$< 2.0 \times 10^{-3}$	CL=90%	2360
$K_3^*(1780)^0\gamma$		$< 8.3 \times 10^{-5}$	CL=90%	2341
$K_4^*(2045)^0\gamma$		$< 4.3 \times 10^{-3}$	CL=90%	2243
Light unflavored meson modes				
$\rho^0\gamma$		$(8.6 \pm 1.5) \times 10^{-7}$		2583
$\rho^0 X(214),\ X \to \mu^+\mu^-$	[yyy]	$< 1.73 \times 10^{-8}$	CL=90%	–
$\omega\gamma$		$(4.4 {}^{+1.8}_{-1.6}) \times 10^{-7}$		2582
$\phi\gamma$		$< 1.0 \times 10^{-7}$	CL=90%	2541
$\pi^+\pi^-$		$(5.12\pm 0.19) \times 10^{-6}$		2636
$\pi^0\pi^0$		$(1.59\pm 0.26) \times 10^{-6}$	S=1.4	2636
$\eta\pi^0$		$(4.1 \pm 1.7) \times 10^{-7}$		2610
$\eta\eta$		$< 1.0 \times 10^{-6}$	CL=90%	2582
$\eta'\pi^0$		$(1.2 \pm 0.6) \times 10^{-6}$	S=1.7	2551
$\eta'\eta'$		$< 1.7 \times 10^{-6}$	CL=90%	2460
$\eta'\eta$		$< 1.2 \times 10^{-6}$	CL=90%	2523
$\eta'\rho^0$		$< 1.3 \times 10^{-6}$	CL=90%	2492
$\eta' f_0(980),\ f_0 \to \pi^+\pi^-$		$< 9 \times 10^{-7}$	CL=90%	2454
$\eta\rho^0$		$< 1.5 \times 10^{-6}$	CL=90%	2553
$\eta f_0(980),\ f_0 \to \pi^+\pi^-$		$< 4 \times 10^{-7}$	CL=90%	2516
$\omega\eta$		$(9.4 {}^{+4.0}_{-3.1}) \times 10^{-7}$		2552
$\omega\eta'$		$(1.0 {}^{+0.5}_{-0.4}) \times 10^{-6}$		2491
$\omega\rho^0$		$< 1.6 \times 10^{-6}$	CL=90%	2522
$\omega f_0(980),\ f_0 \to \pi^+\pi^-$		$< 1.5 \times 10^{-6}$	CL=90%	2485
$\omega\omega$		$(1.2 \pm 0.4) \times 10^{-6}$		2521
$\phi\pi^0$		$< 1.5 \times 10^{-7}$	CL=90%	2540
$\phi\eta$		$< 5 \times 10^{-7}$	CL=90%	2511
$\phi\eta'$		$< 5 \times 10^{-7}$	CL=90%	2448
$\phi\pi^+\pi^-$		$(1.8 \pm 0.5) \times 10^{-7}$		2533
$\phi\rho^0$		$< 3.3 \times 10^{-7}$	CL=90%	2480
$\phi f_0(980),\ f_0 \to \pi^+\pi^-$		$< 3.8 \times 10^{-7}$	CL=90%	2441
$\phi\omega$		$< 7 \times 10^{-7}$	CL=90%	2479
$\phi\phi$		$< 2.7 \times 10^{-8}$	CL=90%	2435
$a_0(980)^\pm\pi^\mp,\ a_0^\pm \to \eta\pi^\pm$		$< 3.1 \times 10^{-6}$	CL=90%	–
$a_0(1450)^\pm\pi^\mp,\ a_0^\pm \to \eta\pi^\pm$		$< 2.3 \times 10^{-6}$	CL=90%	–
$\pi^+\pi^-\pi^0$		$< 7.2 \times 10^{-4}$	CL=90%	2631
$\rho^0\pi^0$		$(2.0 \pm 0.5) \times 10^{-6}$		2581
$\rho^\mp\pi^\pm$	[bb]	$(2.30\pm 0.23) \times 10^{-5}$		2581
$\pi^+\pi^-\pi^+\pi^-$		$< 1.12 \times 10^{-5}$	CL=90%	2621
$\rho^0\pi^+\pi^-$		$< 8.8 \times 10^{-6}$	CL=90%	2575
$\rho^0\rho^0$		$(9.6 \pm 1.5) \times 10^{-7}$		2523
$f_0(980)\pi^+\pi^-,\ f_0 \to \pi^+\pi^-$		$< 3.0 \times 10^{-6}$	CL=90%	–
$\rho^0 f_0(980),\ f_0 \to \pi^+\pi^-$		$(7.8 \pm 2.5) \times 10^{-7}$		2486
$f_0(980) f_0(980),\ f_0 \to \pi^+\pi^-,\ f_0 \to \pi^+\pi^-$		$< 1.9 \times 10^{-7}$	CL=90%	2447
$f_0(980) f_0(980),\ f_0 \to \pi^+\pi^-,\ f_0 \to K^+K^-$		$< 2.3 \times 10^{-7}$	CL=90%	2447
$a_1(1260)^\mp\pi^\pm$	[bb]	$(2.6 \pm 0.5) \times 10^{-5}$	S=1.9	2494
$a_2(1320)^\mp\pi^\pm$	[bb]	$< 6.3 \times 10^{-6}$	CL=90%	2473
$\pi^+\pi^-\pi^0\pi^0$		$< 3.1 \times 10^{-3}$	CL=90%	2622

$\rho^+\rho^-$	$(2.77\pm 0.19)\times 10^{-5}$		2523
$a_1(1260)^0\pi^0$	$< 1.1 \times 10^{-3}$	CL=90%	2495
$\omega\pi^0$	$< 5 \times 10^{-7}$	CL=90%	2580
$\pi^+\pi^+\pi^-\pi^-\pi^0$	$< 9.0 \times 10^{-3}$	CL=90%	2609
$a_1(1260)^+\rho^-$	$< 6.1 \times 10^{-5}$	CL=90%	2433
$a_1(1260)^0\rho^0$	$< 2.4 \times 10^{-3}$	CL=90%	2433
$b_1^\mp\pi^\pm$, $b_1^\mp \to \omega\pi^\mp$	$(1.09\pm 0.15)\times 10^{-5}$		–
$b_1^0\pi^0$, $b_1^0 \to \omega\pi^0$	$< 1.9 \times 10^{-6}$	CL=90%	–
$b_1^-\rho^+$, $b_1^- \to \omega\pi^-$	$< 1.4 \times 10^{-6}$	CL=90%	–
$b_1^0\rho^0$, $b_1^0 \to \omega\pi^0$	$< 3.4 \times 10^{-6}$	CL=90%	–
$\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-$	$< 3.0 \times 10^{-3}$	CL=90%	2592
$a_1(1260)^+a_1(1260)^-$, $a_1^+ \to 2\pi^+\pi^-$, $a_1^- \to 2\pi^-\pi^+$	$(1.18\pm 0.31)\times 10^{-5}$		2336
$\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-\pi^0$	< 1.1 %	CL=90%	2572

Baryon modes

$p\overline{p}$	$(1.25\pm 0.32)\times 10^{-8}$		2467
$p\overline{p}\pi^+\pi^-$	$(2.87\pm 0.19)\times 10^{-6}$		2406
$p\overline{p}K^+\pi^-$	$(6.3 \pm 0.5)\times 10^{-6}$		2306
$p\overline{p}K^0$	$(2.66\pm 0.32)\times 10^{-6}$		2347
$\Theta(1540)^+\overline{p}$, $\Theta^+ \to pK_S^0$	[zzz] $< 5 \times 10^{-8}$	CL=90%	2318
$f_J(2220)K^0$, $f_J \to p\overline{p}$	$< 4.5 \times 10^{-7}$	CL=90%	2135
$p\overline{p}K^*(892)^0$	$(1.24^{+0.28}_{-0.25})\times 10^{-6}$		2216
$f_J(2220)K_0^*$, $f_J \to p\overline{p}$	$< 1.5 \times 10^{-7}$	CL=90%	–
$p\overline{p}K^+K^-$	$(1.21\pm 0.32)\times 10^{-7}$		2179
$p\overline{p}\pi^0$	$(5.0 \pm 1.9)\times 10^{-7}$		2440
$pp\overline{p}\overline{p}$	$< 2.0 \times 10^{-7}$	CL=90%	1735
$p\overline{\Lambda}\pi^-$	$(3.14\pm 0.29)\times 10^{-6}$		2401
$p\overline{\Lambda}\pi^-\gamma$	$< 6.5 \times 10^{-7}$	CL=90%	2401
$p\overline{\Sigma}(1385)^-$	$< 2.6 \times 10^{-7}$	CL=90%	2363
$\Delta(1232)^+\overline{p} + \Delta(1232)^-p$	$< 1.6 \times 10^{-6}$		–
$\Delta^0\overline{\Lambda}$	$< 9.3 \times 10^{-7}$	CL=90%	2364
$p\overline{\Lambda}K^-$	$< 8.2 \times 10^{-7}$	CL=90%	2308
$p\overline{\Lambda}D^-$	$(2.5 \pm 0.4)\times 10^{-5}$		1765
$p\overline{\Lambda}D^{*-}$	$(3.4 \pm 0.8)\times 10^{-5}$		1685
$p\overline{\Sigma}^0\pi^-$	$< 3.8 \times 10^{-6}$	CL=90%	2383
$\overline{\Lambda}\Lambda$	$< 3.2 \times 10^{-7}$	CL=90%	2392
$\overline{\Lambda}\Lambda K^0$	$(4.8 ^{+1.0}_{-0.9})\times 10^{-6}$		2250
$\overline{\Lambda}\Lambda K^{*0}$	$(2.5 ^{+0.9}_{-0.8})\times 10^{-6}$		2098
$\overline{\Lambda}\Lambda D^0$	$(1.00^{+0.30}_{-0.26})\times 10^{-5}$		1662
$D^0\Sigma^0\overline{\Lambda}$+ c.c.	$< 3.1 \times 10^{-5}$	CL=90%	1611
$\Delta^0\overline{\Delta}^0$	$< 1.5 \times 10^{-3}$	CL=90%	2335
$\Delta^{++}\overline{\Delta}^{--}$	$< 1.1 \times 10^{-4}$	CL=90%	2335
$\overline{D}^0 p\overline{p}$	$(1.04\pm 0.07)\times 10^{-4}$		1863
$D_s^-\overline{\Lambda}p$	$(2.8 \pm 0.9)\times 10^{-5}$		1710
$\overline{D}^*(2007)^0 p\overline{p}$	$(9.9 \pm 1.1)\times 10^{-5}$		1788
$D^*(2010)^- p\overline{n}$	$(1.4 \pm 0.4)\times 10^{-3}$		1785
$D^- p\overline{p}\pi^+$	$(3.32\pm 0.31)\times 10^{-4}$		1786
$D^*(2010)^- p\overline{p}\pi^+$	$(4.7 \pm 0.5)\times 10^{-4}$	S=1.2	1708
$\overline{D}^0 p\overline{p}\pi^+\pi^-$	$(3.0 \pm 0.5)\times 10^{-4}$		1708
$\overline{D}^{*0} p\overline{p}\pi^+\pi^-$	$(1.9 \pm 0.5)\times 10^{-4}$		1623
$\Theta_c\overline{p}\pi^+$, $\Theta_c \to D^-p$	$< 9 \times 10^{-6}$	CL=90%	–

$\Theta_c \overline{p} \pi^+$, $\Theta_c \to D^{*-} p$		<	1.4	$\times 10^{-5}$ CL=90%	–
$\overline{\Sigma}_c^{--} \Delta^{++}$		<	8	$\times 10^{-4}$ CL=90%	1839
$\overline{\Lambda}_c^- p \pi^+ \pi^-$			(1.02± 0.14)	$\times 10^{-3}$ S=1.3	1934
$\overline{\Lambda}_c^- p$			(1.54± 0.18)	$\times 10^{-5}$	2021
$\overline{\Lambda}_c^- p \pi^0$			(1.55± 0.19)	$\times 10^{-4}$	1982
$\Sigma_c(2455)^- p$		<	2.4	$\times 10^{-5}$	–
$\overline{\Lambda}_c^- p \pi^+ \pi^- \pi^0$		<	5.07	$\times 10^{-3}$ CL=90%	1883
$\overline{\Lambda}_c^- p \pi^+ \pi^- \pi^+ \pi^-$		<	2.74	$\times 10^{-3}$ CL=90%	1821
$\overline{\Lambda}_c^- p \pi^+ \pi^-$ (nonresonant)			(5.5 ± 1.0)	$\times 10^{-4}$ S=1.3	1934
$\overline{\Sigma}_c(2520)^{--} p \pi^+$			(1.02± 0.18)	$\times 10^{-4}$	1860
$\overline{\Sigma}_c(2520)^0 p \pi^-$		<	3.1	$\times 10^{-5}$ CL=90%	1860
$\overline{\Sigma}_c(2455)^0 p \pi^-$			(1.08± 0.16)	$\times 10^{-4}$	1895
$\overline{\Sigma}_c(2455)^0 N^0$, $N^0 \to p \pi^-$			(6.4 ± 1.7)	$\times 10^{-5}$	–
$\overline{\Sigma}_c(2455)^{--} p \pi^+$			(1.83± 0.24)	$\times 10^{-4}$	1895
$\Lambda_c^- p K^+ \pi^-$			(3.4 ± 0.7)	$\times 10^{-5}$	1786
$\overline{\Sigma}_c(2455)^{--} p K^+$, $\overline{\Sigma}_c^{--} \to \overline{\Lambda}_c^- \pi^-$			(8.8 ± 2.5)	$\times 10^{-6}$	1754
$\Lambda_c^- p K^*(892)^0$		<	2.42	$\times 10^{-5}$ CL=90%	1647
$\Lambda_c^- p K^+ K^-$			(2.0 ± 0.4)	$\times 10^{-5}$	1588
$\Lambda_c^- p \phi$		<	1.0	$\times 10^{-5}$ CL=90%	1567
$\Lambda_c^- p \overline{p} p$		<	2.8	$\times 10^{-6}$	677
$\overline{\Lambda}_c^- \Lambda K^+$			(4.8 ± 1.1)	$\times 10^{-5}$	1767
$\overline{\Lambda}_c^- \Lambda_c^+$		<	1.6	$\times 10^{-5}$ CL=95%	1319
$\overline{\Lambda}_c(2593)^-$ / $\overline{\Lambda}_c(2625)^- p$		<	1.1	$\times 10^{-4}$ CL=90%	–
$\overline{\Xi}_c^- \Lambda_c^+$			(1.2 ± 0.8)	$\times 10^{-3}$	1147
$\overline{\Xi}_c^- \Lambda_c^+$, $\overline{\Xi}_c^- \to \Xi^+ \pi^- \pi^-$			(2.4 ± 1.1)	$\times 10^{-5}$ S=1.8	1147
$\overline{\Xi}_c^- \Lambda_c^+$, $\overline{\Xi}_c^- \to \overline{p} K^+ \pi^-$			(5.3 ± 1.7)	$\times 10^{-6}$	–
$\Lambda_c^+ \Lambda_c^- K^0$			(4.0 ± 0.9)	$\times 10^{-4}$	732
$\overline{\Xi}_c(2930)^- \Lambda_c^+$, $\overline{\Xi}_c^- \to \Lambda_c^- K^0$			(2.4 ± 0.6)	$\times 10^{-4}$	–

Lepton Family number (*LF*) or Lepton number (*L*) or Baryon number (*B*) violating modes, or/and $\Delta B = 1$ weak neutral current (*B1*) modes

$\gamma\gamma$	*B1*		<	3.2	$\times 10^{-7}$ CL=90%	2640
$e^+ e^-$	*B1*		<	8.3	$\times 10^{-8}$ CL=90%	2640
$e^+ e^- \gamma$	*B1*		<	1.2	$\times 10^{-7}$ CL=90%	2640
$\mu^+ \mu^-$	*B1*			($1.1 ^{+1.4}_{-1.3}$)	$\times 10^{-10}$ S=1.6	2638
$\mu^+ \mu^- \gamma$	*B1*		<	1.6	$\times 10^{-7}$ CL=90%	2638
$\mu^+ \mu^- \mu^+ \mu^-$	*B1*		<	6.9	$\times 10^{-10}$ CL=95%	2629
$S P$, $S \to \mu^+ \mu^-$, $P \to \mu^+ \mu^-$	*B1*	[aaaa]	<	6.0	$\times 10^{-10}$ CL=95%	–
$\tau^+ \tau^-$	*B1*		<	2.1	$\times 10^{-3}$ CL=95%	1952
$\pi^0 \ell^+ \ell^-$	*B1*		<	5.3	$\times 10^{-8}$ CL=90%	2638
$\pi^0 e^+ e^-$	*B1*		<	8.4	$\times 10^{-8}$ CL=90%	2638
$\pi^0 \mu^+ \mu^-$	*B1*		<	6.9	$\times 10^{-8}$ CL=90%	2634
$\eta \ell^+ \ell^-$	*B1*		<	6.4	$\times 10^{-8}$ CL=90%	2611
$\eta e^+ e^-$	*B1*		<	1.08	$\times 10^{-7}$ CL=90%	2611
$\eta \mu^+ \mu^-$	*B1*		<	1.12	$\times 10^{-7}$ CL=90%	2607
$\pi^0 \nu \overline{\nu}$	*B1*		<	9	$\times 10^{-6}$ CL=90%	2638
$K^0 \ell^+ \ell^-$	*B1*	[lll]		($3.1 ^{+0.8}_{-0.7}$)	$\times 10^{-7}$	2616
$K^0 e^+ e^-$	*B1*			($1.6 ^{+1.0}_{-0.8}$)	$\times 10^{-7}$	2616
$K^0 \mu^+ \mu^-$	*B1*			(3.39± 0.34)	$\times 10^{-7}$	2612

$K^0 \nu\overline{\nu}$	B1		<	2.6	$\times 10^{-5}$	CL=90%	2616
$\rho^0 \nu\overline{\nu}$	B1		<	4.0	$\times 10^{-5}$	CL=90%	2583
$K^*(892)^0 \ell^+ \ell^-$	B1	[lll]	(	$9.9 \ {}^{+\ 1.2}_{-\ 1.1}$	$) \times 10^{-7}$		2565
$K^*(892)^0 e^+ e^-$	B1		(	$1.03 {}^{+\ 0.19}_{-\ 0.17}$	$) \times 10^{-6}$		2565
$K^*(892)^0 \mu^+ \mu^-$	B1		(	9.4 ± 0.5	$) \times 10^{-7}$		2560
$\pi^+ \pi^- \mu^+ \mu^-$	B1		(	2.1 ± 0.5	$) \times 10^{-8}$		2626
$K^*(892)^0 \nu\overline{\nu}$	B1		<	1.8	$\times 10^{-5}$	CL=90%	2565
invisible	B1		<	2.4	$\times 10^{-5}$	CL=90%	–
$\nu\overline{\nu}\gamma$	B1		<	1.7	$\times 10^{-5}$	CL=90%	2640
$\phi\nu\overline{\nu}$	B1		<	1.27	$\times 10^{-4}$	CL=90%	2541
$e^\pm \mu^\mp$	LF	[bb]	<	1.0	$\times 10^{-9}$	CL=90%	2639
$\pi^0 e^\pm \mu^\mp$	LF		<	1.4	$\times 10^{-7}$	CL=90%	2637
$K^0 e^\pm \mu^\mp$	LF		<	2.7	$\times 10^{-7}$	CL=90%	2615
$K^*(892)^0 e^+ \mu^-$	LF		<	1.6	$\times 10^{-7}$	CL=90%	2563
$K^*(892)^0 e^- \mu^+$	LF		<	1.2	$\times 10^{-7}$	CL=90%	2563
$K^*(892)^0 e^\pm \mu^\mp$	LF		<	1.8	$\times 10^{-7}$	CL=90%	2563
$e^\pm \tau^\mp$	LF	[bb]	<	2.8	$\times 10^{-5}$	CL=90%	2341
$\mu^\pm \tau^\mp$	LF	[bb]	<	1.4	$\times 10^{-5}$	CL=95%	2339
$\Lambda_c^+ \mu^-$	L,B		<	1.4	$\times 10^{-6}$	CL=90%	2143
$\Lambda_c^+ e^-$	L,B		<	4	$\times 10^{-6}$	CL=90%	2145

$B^\pm/B^0$ ADMIXTURE

CP violation

$A_{CP}(B \to K^*(892)\gamma) = -0.003 \pm 0.011$
$A_{CP}(B \to s\gamma) = 0.015 \pm 0.011$
$A_{CP}(B \to (s+d)\gamma) = 0.010 \pm 0.031$
$A_{CP}(B \to X_s \ell^+ \ell^-) = 0.04 \pm 0.11$
$A_{CP}(B \to X_s \ell^+ \ell^-)$ $(1.0 < q^2 < 6.0$ GeV$^2/c^4) = -0.06 \pm 0.22$
$A_{CP}(B \to X_s \ell^+ \ell^-)$ $(10.1 < q^2 < 12.9$ or $q^2 > 14.2$ GeV$^2/c^4) = 0.19 \pm 0.18$
$A_{CP}(B \to K^* e^+ e^-) = -0.18 \pm 0.15$
$A_{CP}(B \to K^* \mu^+ \mu^-) = -0.03 \pm 0.13$
$A_{CP}(B \to K^* \ell^+ \ell^-) = -0.04 \pm 0.07$
$A_{CP}(B \to \eta\,\text{anything}) = -0.13^{+0.04}_{-0.05}$
$\Delta A_{CP}(X_s\gamma) = A_{CP}(B^\pm \to X_s\gamma) - A_{CP}(B^0 \to X_s\gamma) = 0.041 \pm 0.023$
$\overline{A}_{CP}(B \to X_s\gamma) = (A_{CP}(B^+ \to X_s\gamma) + A_{CP}(B^0 \to X_s\gamma))/2 = 0.009 \pm 0.012$
$\Delta A_{CP}(B \to K^*\gamma) = A_{CP}(B^+ \to K^{*+}\gamma) - A_{CP}(B^0 \to K^{*0}\gamma) = 0.024 \pm 0.028$
$\overline{A}_{CP}(B \to K^*\gamma) = (A_{CP}(B^+ \to K^{*+}\gamma) + A_{CP}(B^0 \to K^{*0}\gamma))/2 = -0.001 \pm 0.014$

The branching fraction measurements are for an admixture of B mesons at the $\Upsilon(4S)$. The values quoted assume that B($\Upsilon(4S) \to B\overline{B}$) = 100%.

For inclusive branching fractions, *e.g.*, $B \to D^\pm$ *anything*, the treatment of multiple D's in the final state must be defined. One possibility would be to count the number of events with one-or-more D's and divide by the total number of B's. Another possibility would be to count the total number of D's and divide by the total number of B's, which is the definition of average multiplicity. The two definitions are identical if only one D is allowed in the final state.

Even though the "one-or-more" definition seems sensible, for practical reasons inclusive branching fractions are almost always measured using the multiplicity definition. For heavy final state particles, authors call their results inclusive branching fractions while for light particles some authors call their results multiplicities. In the B sections, we list all results as inclusive branching fractions, adopting a multiplicity definition. This means that inclusive branching fractions can exceed 100% and that inclusive partial widths can exceed total widths, just as inclusive cross sections can exceed total cross section.

$\overline{B}$ modes are charge conjugates of the modes below. Reactions indicate the weak decay vertex and do not include mixing.

B DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
		Semileptonic and leptonic modes		
$\ell^+ \nu_\ell$ anything	[*lll,bbaa*]	(10.86 ± 0.16) %		–
$D^- \ell^+ \nu_\ell$ anything	[*lll*]	(2.6 ± 0.5) %		–
$\overline{D}^0 \ell^+ \nu_\ell$ anything	[*lll*]	(7.3 ± 1.5) %		–
$\overline{D} \ell^+ \nu_\ell$		(2.42 ± 0.12) %		2310
$D^{*-} \ell^+ \nu_\ell$ anything	[*ccaa*]	(6.7 ± 1.3) $\times 10^{-3}$		–
$D^* \ell^+ \nu_\ell$	[*ddaa*]	(4.95 ± 0.11) %		2257
$\overline{D}^{**} \ell^+ \nu_\ell$	[*lll,eeaa*]	(2.7 ± 0.7) %		–
$\overline{D}_1(2420) \ell^+ \nu_\ell$ anything		(3.8 ± 1.3) $\times 10^{-3}$	S=2.4	–
$D \pi \ell^+ \nu_\ell$ anything + $D^* \pi \ell^+ \nu_\ell$ anything		(2.6 ± 0.5) %	S=1.5	–
$D \pi \ell^+ \nu_\ell$ anything		(1.5 ± 0.6) %		–
$D^* \pi \ell^+ \nu_\ell$ anything		(1.9 ± 0.4) %		–
$\overline{D}^*_2(2460) \ell^+ \nu_\ell$ anything		(4.4 ± 1.6) $\times 10^{-3}$		–
$D^{*-} \pi^+ \ell^+ \nu_\ell$ anything		(1.00 ± 0.34) %		–
$\overline{D} \pi^+ \pi^- \ell^+ \nu_\ell$		(1.62 ± 0.32) $\times 10^{-3}$		2301
$\overline{D}^* \pi^+ \pi^- \ell^+ \nu_\ell$		(9.4 ± 3.2) $\times 10^{-4}$		2247
$D_s^- \ell^+ \nu_\ell$ anything	[*lll*]	< 7 $\times 10^{-3}$	CL=90%	–
$D_s^- \ell^+ \nu_\ell K^+$ anything	[*lll*]	< 5 $\times 10^{-3}$	CL=90%	–
$D_s^- \ell^+ \nu_\ell K^0$ anything	[*lll*]	< 7 $\times 10^{-3}$	CL=90%	–
$X_c \ell^+ \nu_\ell$		(10.65 ± 0.16) %		–
$X_u \ell^+ \nu_\ell$		(2.13 ± 0.30) $\times 10^{-3}$		–
$K^+ \ell^+ \nu_\ell$ anything	[*lll*]	(6.3 ± 0.6) %		–
$K^- \ell^+ \nu_\ell$ anything	[*lll*]	(10 ± 4) $\times 10^{-3}$		–
$K^0 / \overline{K}^0 \ell^+ \nu_\ell$ anything	[*lll*]	(4.6 ± 0.5) %		–
$\overline{D} \tau^+ \nu_\tau$		(9.9 ± 1.2) $\times 10^{-3}$		1911
$D^* \tau^+ \nu_\tau$		(1.50 ± 0.08) %		1838
		***D*, *D**, or *D*$_s$ modes**		
$D^\pm$ anything		(23.1 ± 1.2) %		–
$D^0 / \overline{D}^0$ anything		(61.5 ± 2.9) %	S=1.3	–
$D^*(2010)^\pm$ anything		(22.5 ± 1.5) %		–
$D^*(2007)^0$ anything		(26.0 ± 2.7) %		–
$D_s^\pm$ anything	[*bb*]	(8.3 ± 0.8) %		–
$D_s^{*\pm}$ anything		(6.3 ± 1.0) %		–
$D_s^{*\pm} \overline{D}^{(*)}$		(3.4 ± 0.6) %		–
$D^{(*)} \overline{D}^{(*)} K^0$ + $D^{(*)} \overline{D}^{(*)} K^\pm$	[*bb,ffaa*]	(7.1 $^{+2.7}_{-1.7}$) %		–
$b \to c \overline{c} s$		(22 ± 4) %		–
$D_s^{(*)} \overline{D}^{(*)}$	[*bb,ffaa*]	(3.9 ± 0.4) %		–
$D^* D^*(2010)^\pm$	[*bb*]	< 5.9 $\times 10^{-3}$	CL=90%	1711
$D D^*(2010)^\pm$ + $D^* D^\pm$	[*bb*]	< 5.5 $\times 10^{-3}$	CL=90%	–

$D D^{\pm}$	[bb]	$< 3.1 \times 10^{-3}$	CL=90%	1866
$D_s{}^{(*)\pm} \overline{D}{}^{(*)} X(n\pi^{\pm})$	[bb,ffaa]	$(9 ^{+5}_{-4})\ \%$		–
$D^*(2010)\gamma$		$< 1.1 \times 10^{-3}$	CL=90%	2257
$D_s^+\pi^-$, $D_s^{*+}\pi^-$, $D_s^+\rho^-$, $D_s^{*+}\rho^-$, $D_s^+\pi^0$, $D_s^{*+}\pi^0$, $D_s^+\eta$, $D_s^{*+}\eta$, $D_s^+\rho^0$, $D_s^{*+}\rho^0$, $D_s^+\omega$, $D_s^{*+}\omega$	[bb]	$< 4 \times 10^{-4}$	CL=90%	–
$D_{s1}(2536)^+$ anything		$< 9.5 \times 10^{-3}$	CL=90%	–

Charmonium modes

$J/\psi(1S)$ anything		$(1.094 \pm 0.032)\ \%$	S=1.1	–
$J/\psi(1S)$ (direct) anything		$(7.8 \pm 0.4) \times 10^{-3}$	S=1.1	–
$\psi(2S)$ anything		$(3.07 \pm 0.21) \times 10^{-3}$		–
$\chi_{c1}(1P)$ anything		$(3.55 \pm 0.27) \times 10^{-3}$	S=1.3	–
$\chi_{c1}(1P)$ (direct) anything		$(3.08 \pm 0.19) \times 10^{-3}$		–
$\chi_{c2}(1P)$ anything		$(10.0 \pm 1.7) \times 10^{-4}$	S=1.6	–
$\chi_{c2}(1P)$ (direct) anything		$(7.5 \pm 1.1) \times 10^{-4}$		–
$\eta_c(1S)$ anything		$< 9 \times 10^{-3}$	CL=90%	–
$K\chi_{c1}(3872)$, $\chi_{c1} \to D^0 \overline{D}{}^0 \pi^0$		$(1.2 \pm 0.4) \times 10^{-4}$		1141
$K\chi_{c1}(3872)$, $\chi_{c1} \to D^{*0} D^0$		$(8.0 \pm 2.2) \times 10^{-5}$		1141
$K X(3940)$, $X \to D^{*0} D^0$		$< 6.7 \times 10^{-5}$	CL=90%	1084
$K X(3915)$, $X \to \omega J/\psi$	[ggaa]	$(7.1 \pm 3.4) \times 10^{-5}$		1103

***K* or *K** modes**

$K^{\pm}$ anything	[bb]	$(78.9 \pm 2.5)\ \%$		–
K^+ anything		$(66 \pm 5)\ \%$		–
K^- anything		$(13 \pm 4)\ \%$		–
$K^0 / \overline{K}{}^0$ anything	[bb]	$(64 \pm 4)\ \%$		–
$K^*(892)^{\pm}$ anything		$(18 \pm 6)\ \%$		–
$K^*(892)^0 / \overline{K}{}^*(892)^0$ anything	[bb]	$(14.6 \pm 2.6)\ \%$		–
$K^*(892)\gamma$		$(4.2 \pm 0.6) \times 10^{-5}$		2565
$\eta K \gamma$		$(8.5 ^{+1.8}_{-1.6}) \times 10^{-6}$		2588
$K_1(1400)\gamma$		$< 1.27 \times 10^{-4}$	CL=90%	2454
$K_2^*(1430)\gamma$		$(1.7 ^{+0.6}_{-0.5}) \times 10^{-5}$		2447
$K_2(1770)\gamma$		$< 1.2 \times 10^{-3}$	CL=90%	2342
$K_3^*(1780)\gamma$		$< 3.7 \times 10^{-5}$	CL=90%	2341
$K_4^*(2045)\gamma$		$< 1.0 \times 10^{-3}$	CL=90%	2243
$K\eta'(958)$		$(8.3 \pm 1.1) \times 10^{-5}$		2528
$K^*(892)\eta'(958)$		$(4.1 \pm 1.1) \times 10^{-6}$		2472
$K\eta$		$< 5.2 \times 10^{-6}$	CL=90%	2588
$K^*(892)\eta$		$(1.8 \pm 0.5) \times 10^{-5}$		2534
$K\phi\phi$		$(2.3 \pm 0.9) \times 10^{-6}$		2306
$\overline{b} \to \overline{s}\gamma$		$(3.49 \pm 0.19) \times 10^{-4}$		–
$\overline{b} \to \overline{d}\gamma$		$(9.2 \pm 3.0) \times 10^{-6}$		–
$\overline{b} \to \overline{s}$ gluon		$< 6.8\ \%$	CL=90%	–
η anything		$(2.6 ^{+0.5}_{-0.8}) \times 10^{-4}$		–
η' anything		$(4.2 \pm 0.9) \times 10^{-4}$		–
K^+ gluon (charmless)		$< 1.87 \times 10^{-4}$	CL=90%	–
K^0 gluon (charmless)		$(1.9 \pm 0.7) \times 10^{-4}$		–

Light unflavored meson modes				
$\rho\gamma$		$(1.39 \pm 0.25) \times 10^{-6}$	S=1.2	2583
$\rho/\omega\gamma$		$(1.30 \pm 0.23) \times 10^{-6}$	S=1.2	–
$\pi^{\pm}$ anything	[bb,hhaa]	(358 ± 7) %		–
π^0 anything		(235 ± 11) %		–
η anything		(17.6 ± 1.6) %		–
ρ^0 anything		(21 ± 5) %		–
ω anything		< 81 %	CL=90%	–
ϕ anything		(3.43 ± 0.12) %		–
$\phi K^*(892)$		$< 2.2 \times 10^{-5}$	CL=90%	2460
π^+ gluon (charmless)		$(3.7 \pm 0.8) \times 10^{-4}$		–
Baryon modes				
Λ_c^+ / $\overline{\Lambda}_c^-$ anything		(3.6 ± 0.4) %		–
Λ_c^+ anything		< 1.3 %	CL=90%	–
$\overline{\Lambda}_c^-$ anything		< 7 %	CL=90%	–
$\overline{\Lambda}_c^- \ell^+$ anything		$< 9 \times 10^{-4}$	CL=90%	–
$\overline{\Lambda}_c^- e^+$ anything		$< 1.8 \times 10^{-3}$	CL=90%	–
$\overline{\Lambda}_c^- \mu^+$ anything		$< – 1.4 \times 10^{-3}$	CL=90%	–
$\overline{\Lambda}_c^- p$ anything		(2.04 ± 0.33) %		–
$\overline{\Lambda}_c^- p e^+ \nu_e$		$< 8 \times 10^{-4}$	CL=90%	2021
$\overline{\Sigma}_c^{--}$ anything		$(3.3 \pm 1.7) \times 10^{-3}$		–
$\overline{\Sigma}_c^-$ anything		$< 8 \times 10^{-3}$	CL=90%	–
$\overline{\Sigma}_c^0$ anything		$(3.7 \pm 1.7) \times 10^{-3}$		–
$\overline{\Sigma}_c^0 N (N = p$ or $n)$		$< 1.2 \times 10^{-3}$	CL=90%	1938
Ξ_c^0 anything, $\Xi_c^0 \to \Xi^- \pi^+$		$(1.93 \pm 0.30) \times 10^{-4}$	S=1.1	–
Ξ_c^+, $\Xi_c^+ \to \Xi^- \pi^+ \pi^+$		$(4.5 {}^{+1.3}_{-1.2}) \times 10^{-4}$		–
$p/\overline{p}$ anything	[bb]	(8.0 ± 0.4) %		–
$p/\overline{p}$ (direct) anything	[bb]	(5.5 ± 0.5) %		–
$\overline{p} e^+ \nu_e$ anything		$< 5.9 \times 10^{-4}$	CL=90%	–
$\Lambda/\overline{\Lambda}$ anything	[bb]	(4.0 ± 0.5) %		–
$\Xi^-/\overline{\Xi}^+$ anything	[bb]	$(2.7 \pm 0.6) \times 10^{-3}$		–
baryons anything		(6.8 ± 0.6) %		–
$p\overline{p}$ anything		(2.47 ± 0.23) %		–
$\Lambda\overline{p}/\overline{\Lambda}p$ anything	[bb]	(2.5 ± 0.4) %		–
$\Lambda\overline{\Lambda}$ anything		$< 5 \times 10^{-3}$	CL=90%	–
Lepton Family number (LF) violating modes or $\Delta B = 1$ weak neutral current ($B1$) modes				
$s e^+ e^-$	$B1$	$(6.7 \pm 1.7) \times 10^{-6}$	S=2.0	–
$s \mu^+ \mu^-$	$B1$	$(4.3 \pm 1.0) \times 10^{-6}$		–
$s \ell^+ \ell^-$	$B1$ [lll]	$(5.8 \pm 1.3) \times 10^{-6}$	S=1.8	–
$\pi \ell^+ \ell^-$	$B1$	$< 5.9 \times 10^{-8}$	CL=90%	2638
$\pi e^+ e^-$	$B1$	$< 1.10 \times 10^{-7}$	CL=90%	2638
$\pi \mu^+ \mu^-$	$B1$	$< 5.0 \times 10^{-8}$	CL=90%	2634
$K e^+ e^-$	$B1$	$(4.4 \pm 0.6) \times 10^{-7}$		2617
$K^*(892) e^+ e^-$	$B1$	$(1.19 \pm 0.20) \times 10^{-6}$	S=1.2	2565
$K \mu^+ \mu^-$	$B1$	$(4.4 \pm 0.4) \times 10^{-7}$		2612
$K^*(892) \mu^+ \mu^-$	$B1$	$(1.06 \pm 0.09) \times 10^{-6}$		2560
$K \ell^+ \ell^-$	$B1$	$(4.8 \pm 0.4) \times 10^{-7}$		2617
$K^*(892) \ell^+ \ell^-$	$B1$	$(1.05 \pm 0.10) \times 10^{-6}$		2565
$K \nu \overline{\nu}$	$B1$	$< 1.6 \times 10^{-5}$	CL=90%	2617
$K^* \nu \overline{\nu}$	$B1$	$< 2.7 \times 10^{-5}$	CL=90%	–

$\pi \nu \overline{\nu}$	$B1$		$<$	8	$\times 10^{-6}$	CL=90%	2638
$\rho \nu \overline{\nu}$	$B1$		$<$	2.8	$\times 10^{-5}$	CL=90%	2583
$s e^{\pm} \mu^{\mp}$	LF	[bb]	$<$	2.2	$\times 10^{-5}$	CL=90%	–
$\pi e^{\pm} \mu^{\mp}$	LF		$<$	9.2	$\times 10^{-8}$	CL=90%	2637
$\rho e^{\pm} \mu^{\mp}$	LF		$<$	3.2	$\times 10^{-6}$	CL=90%	2582
$K e^{\pm} \mu^{\mp}$	LF		$<$	3.8	$\times 10^{-8}$	CL=90%	2616
$K^*(892) e^{\pm} \mu^{\mp}$	LF		$<$	5.1	$\times 10^{-7}$	CL=90%	2563

See Particle Listings for 4 decay modes that have been seen / not seen.

$B^{\pm}/B^0/B^0_s/b$-baryon ADMIXTURE

These measurements are for an admixture of bottom particles at high energy (LHC, LEP, Tevatron, $Sp\overline{p}S$).

Mean life $\tau = (1.5668 \pm 0.0028) \times 10^{-12}$ s

Mean life $\tau = (1.72 \pm 0.10) \times 10^{-12}$ s Charged b-hadron admixture

Mean life $\tau = (1.58 \pm 0.14) \times 10^{-12}$ s Neutral b-hadron admixture

$\tau_{\text{charged } b-\text{hadron}} / \tau_{\text{neutral } b-\text{hadron}} = 1.09 \pm 0.13$

$|\Delta\tau_b| / \tau_{b,\overline{b}} = -0.001 \pm 0.014$

The branching fraction measurements are for an admixture of B mesons and baryons at energies above the $\Upsilon(4S)$. Only the highest energy results (LHC, LEP, Tevatron, $Sp\overline{p}S$) are used in the branching fraction averages. In the following, we assume that the production fractions are the same at the LHC, LEP, and at the Tevatron.

For inclusive branching fractions, *e.g.*, $B \to D^{\pm}$ anything, the values usually are multiplicities, not branching fractions. They can be greater than one.

The modes below are listed for a $\overline{b}$ initial state. b modes are their charge conjugates. Reactions indicate the weak decay vertex and do not include mixing.

$\overline{b}$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)

PRODUCTION FRACTIONS

The production fractions for weakly decaying b-hadrons at high energy have been calculated from the best values of mean lives, mixing parameters, and branching fractions in this edition by the Heavy Flavor Averaging Group (HFLAV) as described in the note "B^0-$\overline{B}^0$ Mixing" in the B^0 Particle Listings. We no longer provide world averages of the b-hadron production fractions, where results from LEP, Tevatron and LHC are averaged together; indeed the available data (from CDF and LHCb) shows that the fractions depend on the kinematics (in particular the p_T) of the produced b hadron. Hence we would like to list the fractions in Z decays instead, which are well-defined physics observables. The production fractions in $p\overline{p}$ collisions at the Tevatron are also listed at the end of the section. Values assume

$B(\overline{b} \to B^+) = B(\overline{b} \to B^0)$

$B(\overline{b} \to B^+) + B(\overline{b} \to B^0) + B(\overline{b} \to B^0_s) + B(b \to b\text{-baryon}) = 100\%$.

The correlation coefficients between production fractions are also reported:

$cor(B^0_s, b\text{-baryon}) = 0.064$

$cor(B^0_s, B^{\pm}{=}B^0) = -0.633$

$cor(b\text{-baryon}, B^{\pm}{=}B^0) = -0.813$.

The notation for production fractions varies in the literature (f_d, d_{B^0}, $f(b \to \overline{B}^0)$, $\text{Br}(b \to \overline{B}^0)$). We use our own branching fraction notation here, $B(\overline{b} \to B^0)$.

Note these production fractions are b-hadronization fractions, not the conventional branching fractions of b-quark to a B-hadron, which may have considerable dependence on the initial and final state kinematic and production environment.

B^+		(40.8 ± 0.7) %		–
B^0		(40.8 ± 0.7) %		–
B^0_s		(10.0 ± 0.8) %		–
b-baryon		(8.4 ± 1.1) %		–

DECAY MODES

Semileptonic and leptonic modes

ν anything		(23.1 ± 1.5) %		–
$\ell^+ \nu_\ell$ anything	[lll]	(10.69 ± 0.22) %		–
$e^+ \nu_e$ anything		(10.86 ± 0.35) %		–
$\mu^+ \nu_\mu$ anything		$(10.95 {}^{+0.29}_{-0.25})$ %		–
$D^- \ell^+ \nu_\ell$ anything	[lll]	(2.2 ± 0.4) %	S=1.9	–
$D^- \pi^+ \ell^+ \nu_\ell$ anything		$(4.9 \pm 1.9) \times 10^{-3}$		–
$D^- \pi^- \ell^+ \nu_\ell$ anything		$(2.6 \pm 1.6) \times 10^{-3}$		–
$\overline{D}{}^0 \ell^+ \nu_\ell$ anything	[lll]	(6.79 ± 0.34) %		–
$\overline{D}{}^0 \pi^- \ell^+ \nu_\ell$ anything		(1.07 ± 0.27) %		–
$\overline{D}{}^0 \pi^+ \ell^+ \nu_\ell$ anything		$(2.3 \pm 1.6) \times 10^{-3}$		–
$D^{*-} \ell^+ \nu_\ell$ anything	[lll]	(2.75 ± 0.19) %		–
$D^{*-} \pi^- \ell^+ \nu_\ell$ anything		$(6 \pm 7) \times 10^{-4}$		–
$D^{*-} \pi^+ \ell^+ \nu_\ell$ anything		$(4.8 \pm 1.0) \times 10^{-3}$		–
$\overline{D}{}^0_j \ell^+ \nu_\ell$ anything $\times$ B($\overline{D}{}^0_j \to D^{*+} \pi^-$)	[lll,iiaa]	$(2.6 \pm 0.9) \times 10^{-3}$		–
$D^-_j \ell^+ \nu_\ell$ anything $\times$ B($D^-_j \to D^0 \pi^-$)	[lll,iiaa]	$(7.0 \pm 2.3) \times 10^{-3}$		–
$\overline{D}{}^*_2(2460)^0 \ell^+ \nu_\ell$ anything $\times$ B($\overline{D}{}^*_2(2460)^0 \to D^{*-} \pi^+$)		$< 1.4 \times 10^{-3}$	CL=90%	–
$D^*_2(2460)^- \ell^+ \nu_\ell$ anything $\times$ B($D^*_2(2460)^- \to D^0 \pi^-$)		$(4.2 {}^{+1.5}_{-1.8}) \times 10^{-3}$		–
$\overline{D}{}^*_2(2460)^0 \ell^+ \nu_\ell$ anything $\times$ B($\overline{D}{}^*_2(2460)^0 \to D^- \pi^+$)		$(1.6 \pm 0.8) \times 10^{-3}$		–
charmless $\ell \overline{\nu}_\ell$	[lll]	$(1.7 \pm 0.5) \times 10^{-3}$		–
$\tau^+ \nu_\tau$ anything		(2.41 ± 0.23) %		–
$D^{*-} \tau \nu_\tau$ anything		$(9 \pm 4) \times 10^{-3}$		–
$\overline{c} \to \ell^- \overline{\nu}_\ell$ anything	[lll]	(8.02 ± 0.19) %		–
$c \to \ell^+ \nu$ anything		$(1.6 {}^{+0.4}_{-0.5})$ %		–

Charmed meson and baryon modes

$\overline{D}{}^0$ anything		(58.7 ± 2.8) %		–
$D^0 D^\pm_s$ anything	[bb]	$(9.1 {}^{+4.0}_{-2.8})$ %		–
$D^\mp D^\pm_s$ anything	[bb]	$(4.0 {}^{+2.3}_{-1.8})$ %		–
$\overline{D}{}^0 D^0$ anything	[bb]	$(5.1 {}^{+2.0}_{-1.8})$ %		–
$D^0 D^\pm$ anything	[bb]	$(2.7 {}^{+1.8}_{-1.6})$ %		–
$D^\pm D^\mp$ anything	[bb]	$< 9 \times 10^{-3}$	CL=90%	–
D^- anything		(22.7 ± 1.6) %		–
$D^*(2010)^+$ anything		(17.3 ± 2.0) %		–

$D_1(2420)^0$ anything		(5.0 ± 1.5) %		–
$D^*(2010)^{\mp} D_s^{\pm}$ anything	[bb]	($3.3\ ^{+1.6}_{-1.3}$) %		–
$D^0 D^*(2010)^{\pm}$ anything	[bb]	($3.0\ ^{+1.1}_{-0.9}$) %		–
$D^*(2010)^{\pm} D^{\mp}$ anything	[bb]	($2.5\ ^{+1.2}_{-1.0}$) %		–
$D^*(2010)^{\pm} D^*(2010)^{\mp}$ anything	[bb]	(1.2 ± 0.4) %		–
$\overline{D} D$ anything		($10\ ^{+11}_{-10}$) %		–
$D_2^*(2460)^0$ anything		(4.7 ± 2.7) %		–
D_s^- anything		(14.7 ± 2.1) %		–
D_s^+ anything		(10.1 ± 3.1) %		–
Λ_c^+ anything		(7.7 ± 1.1) %		–
$\overline{c} / c$ anything	[hhaa]	(116.2 ± 3.2) %		–
Charmonium modes				
$J/\psi(1S)$ anything		(1.16 ± 0.10) %		–
$\psi(2S)$ anything		(2.86 ± 0.28) $\times 10^{-3}$		–
$\chi_{c0}(1P)$ anything		(1.5 ± 0.6) %		–
$\chi_{c1}(1P)$ anything		(1.4 ± 0.4) %		–
$\chi_{c2}(1P)$ anything		(6.2 ± 2.9) $\times 10^{-3}$		–
$\chi_c(2P)$ anything, $\chi_c \to \phi\phi$		< 2.8 $\times 10^{-7}$	CL=95%	–
$\eta_c(1S)$ anything		(4.5 ± 1.9) %		–
$\eta_c(2S)$ anything, $\eta_c \to \phi\phi$		(3.2 ± 1.7) $\times 10^{-6}$		–
$\chi_{c1}(3872)$ anything, $\chi_{c1} \to \phi\phi$		< 4.5 $\times 10^{-7}$	CL=95%	–
$X(3915)$ anything, $X \to \phi\phi$		< 3.1 $\times 10^{-7}$	CL=95%	–
***K* or *K** modes**				
$\overline{s}\gamma$		(3.1 ± 1.1) $\times 10^{-4}$		–
$\overline{s}\overline{\nu}\nu$	B1	< 6.4 $\times 10^{-4}$	CL=90%	–
$K^{\pm}$ anything		(74 ± 6) %		–
K_S^0 anything		(29.0 ± 2.9) %		–
Pion modes				
$\pi^{\pm}$ anything		(397 ±21) %		–
π^0 anything	[hhaa]	(278 ±60) %		–
ϕ anything		(2.82 ± 0.23) %		–
Baryon modes				
$p/\overline{p}$ anything		(13.1 ± 1.1) %		–
$\Lambda/\overline{\Lambda}$ anything		(5.9 ± 0.6) %		–
b-baryon anything		(10.2 ± 2.8) %		–
Other modes				
charged anything	[hhaa]	(497 ± 7) %		–
hadron$^+$ hadron$^-$		($1.7\ ^{+1.0}_{-0.7}$) $\times 10^{-5}$		–
charmless		(7 ±21) $\times 10^{-3}$		–
$\Delta B = 1$ weak neutral current (*B1*) modes				
$\mu^+\mu^-$ anything	B1	< 3.2 $\times 10^{-4}$	CL=90%	–

B^*

$I(J^P) = \frac{1}{2}(1^-)$
I, J, P need confirmation.

Quantum numbers shown are quark-model predictions.

Mass $m_{B^*} = 5324.70 \pm 0.21$ MeV
$m_{B^*} - m_B = 45.21 \pm 0.21$ MeV
$m_{B^{*+}} - m_{B^+} = 45.37 \pm 0.21$ MeV

$B_1(5721)^+$

$I(J^P) = \frac{1}{2}(1^+)$
I, J, P need confirmation.

Mass $m = 5725.9^{+2.5}_{-2.7}$ MeV
$m_{B_1^+} - m_{B^{*0}} = 401.2^{+2.4}_{-2.7}$ MeV
Full width $\Gamma = 31 \pm 6$ MeV (S = 1.1)

$B_1(5721)^0$

$I(J^P) = \frac{1}{2}(1^+)$
I, J, P need confirmation.

$B_1(5721)^0$ MASS $= 5726.1 \pm 1.3$ MeV (S = 1.2)
$m_{B_1^0} - m_{B^+} = 446.7 \pm 1.3$ MeV (S = 1.2)
$m_{B_1^0} - m_{B^{*+}} = 401.4 \pm 1.2$ MeV (S = 1.2)
Full width $\Gamma = 27.5 \pm 3.4$ MeV (S = 1.1)

$B_2^*(5747)^+$

$I(J^P) = \frac{1}{2}(2^+)$
I, J, P need confirmation.

Mass $m = 5737.2 \pm 0.7$ MeV
$m_{B_2^{*+}} - m_{B^0} = 457.5 \pm 0.7$ MeV
Full width $\Gamma = 20 \pm 5$ MeV (S = 2.2)

$B_2^*(5747)^0$

$I(J^P) = \frac{1}{2}(2^+)$
I, J, P need confirmation.

$B_2^*(5747)^0$ MASS $= 5739.5 \pm 0.7$ MeV (S = 1.4)
$m_{B_2^{*0}} - m_{B_1^0} = 13.4 \pm 1.4$ MeV (S = 1.3)
$m_{B_2^{*0}} - m_{B^+} = 460.2 \pm 0.6$ MeV (S = 1.4)
Full width $\Gamma = 24.2 \pm 1.7$ MeV

$B_J(5970)^+$

$I(J^P) = \frac{1}{2}(?^?)$
I, J, P need confirmation.

Mass $m = 5964 \pm 5$ MeV
$m_{B_J(5970)^+} - m_{B^0} = 685 \pm 5$ MeV
Full width $\Gamma = 62 \pm 20$ MeV

$B_J(5970)^0$

$I(J^P) = \frac{1}{2}(?^?)$
I, J, P need confirmation.

Mass $m = 5971 \pm 5$ MeV
$m_{B_J(5970)^0} - m_{B^+} = 691 \pm 5$ MeV
Full width $\Gamma = 81 \pm 12$ MeV

BOTTOM, STRANGE MESONS ($B = \pm 1$, $S = \mp 1$)

$B_s^0 = s\overline{b}$, $\overline{B}_s^0 = \overline{s}\,b$, similarly for B_s^*'s

B_s^0

$I(J^P) = 0(0^-)$

I, J, P need confirmation. Quantum numbers shown are quark-model predictions.

Mass $m_{B_s^0} = 5366.88 \pm 0.14$ MeV
$m_{B_s^0} - m_B = 87.38 \pm 0.16$ MeV
Mean life $\tau = (1.515 \pm 0.004) \times 10^{-12}$ s
$c\tau = 454.2\ \mu$m
$\Delta\Gamma_{B_s^0} = \Gamma_{B_{sL}^0} - \Gamma_{B_{sH}^0} = (0.085 \pm 0.004) \times 10^{12}\ \text{s}^{-1}$

B_s^0-$\overline{B}_s^0$ mixing parameters

$\Delta m_{B_s^0} = m_{B_{sH}^0} - m_{B_{sL}^0} = (17.749 \pm 0.020) \times 10^{12}\ \hbar\ \text{s}^{-1}$
$= (1.1683 \pm 0.0013) \times 10^{-8}$ MeV
$x_s = \Delta m_{B_s^0}/\Gamma_{B_s^0} = 26.89 \pm 0.07$
$\chi_s = 0.499312 \pm 0.000004$

CP violation parameters in B_s^0

$\text{Re}(\epsilon_{B_s^0})\ /\ (1 + |\epsilon_{B_s^0}|^2) = (-0.15 \pm 0.70) \times 10^{-3}$
$C_{KK}(B_s^0 \to K^+K^-) = 0.14 \pm 0.11$
$S_{KK}(B_s^0 \to K^+K^-) = 0.30 \pm 0.13$
$r_B(B_s^0 \to D_s^\mp K^\pm) = 0.37^{+0.10}_{-0.09}$
$\delta_B(B_s^0 \to D_s^\pm K^\mp) = (358 \pm 14)^\circ$
CP Violation phase $\beta_s = (2.55 \pm 1.15) \times 10^{-2}$ rad
$|\lambda|\ (B_s^0 \to J/\psi(1S)\phi) = 1.012 \pm 0.017$
$|\lambda| = 0.999 \pm 0.017$
A, CP violation parameter $= -0.75 \pm 0.12$
C, CP violation parameter $= 0.19 \pm 0.06$
S, CP violation parameter $= 0.17 \pm 0.06$
$A^L_{CP}(B_s \to J/\psi\overline{K}^*(892)^0) = -0.05 \pm 0.06$
$A^{\parallel}_{CP}(B_s \to J/\psi\overline{K}^*(892)^0) = 0.17 \pm 0.15$
$A^{\perp}_{CP}(B_s \to J/\psi\overline{K}^*(892)^0) = -0.05 \pm 0.10$
$\boldsymbol{A_{CP}(B_s \to \pi^+K^-)} = 0.221 \pm 0.015$
$A_{CP}(B_s^0 \to [K^+K^-]_D\overline{K}^*(892)^0) = -0.04 \pm 0.07$
$A_{CP}(B_s^0 \to [\pi^+K^-]_D K^*(892)^0) = -0.01 \pm 0.04$
$A_{CP}(B_s^0 \to [\pi^+\pi^-]_D K^*(892)^0) = 0.06 \pm 0.13$
$S(B_s^0 \to \phi\gamma) = 0.43 \pm 0.32$
$C(B_s^0 \to \phi\gamma) = 0.11 \pm 0.31$
$A^{\Delta}(B_s \to \phi\gamma) = -0.7 \pm 0.4$
$\Delta a_\perp < 1.2 \times 10^{-12}$ GeV, CL = 95%
$\Delta a_\parallel = (-0.9 \pm 1.5) \times 10^{-14}$ GeV
$\Delta a_X = (1.0 \pm 2.2) \times 10^{-14}$ GeV
$\Delta a_Y = (-3.8 \pm 2.2) \times 10^{-14}$ GeV

$\mathrm{Re}(\xi) = -0.022 \pm 0.033$
$\mathrm{Im}(\xi) = 0.004 \pm 0.011$

These branching fractions all scale with $B(\overline{b} \to B^0_s)$.

The branching fraction $B(B^0_s \to D^-_s \ell^+ \nu_\ell \text{anything})$ is not a pure measurement since the measured product branching fraction $B(\overline{b} \to B^0_s) \times B(B^0_s \to D^-_s \ell^+ \nu_\ell \text{anything})$ was used to determine $B(\overline{b} \to B^0_s)$, as described in the note on "B^0-$\overline{B}^0$ Mixing"

For inclusive branching fractions, *e.g.*, $B \to D^\pm \text{anything}$, the values usually are multiplicities, not branching fractions. They can be greater than one.

B^0_s DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
D^-_s anything		(93 ± 25) %		–
$\ell \nu_\ell X$		(9.6 ± 0.8) %		–
$e^+ \nu X^-$		(9.1 ± 0.8) %		–
$\mu^+ \nu X^-$		(10.2 ± 1.0) %		–
$D^-_s \ell^+ \nu_\ell$ anything	[jjaa]	(8.1 ± 1.3) %		–
$D^{*-}_s \ell^+ \nu_\ell$ anything		(5.4 ± 1.1) %		–
$D_{s1}(2536)^- \mu^+ \nu_\mu$, $D^-_{s1} \to D^{*-} K^0_S$		$(2.7 \pm 0.7) \times 10^{-3}$		–
$D_{s1}(2536)^- X \mu^+ \nu$, $D^-_{s1} \to \overline{D}^0 K^+$		$(4.4 \pm 1.3) \times 10^{-3}$		–
$D_{s2}(2573)^- X \mu^+ \nu$, $D^-_{s2} \to \overline{D}^0 K^+$		$(2.7 \pm 1.0) \times 10^{-3}$		–
$D^-_s \pi^+$		$(3.00 \pm 0.23) \times 10^{-3}$		2320
$D^-_s \rho^+$		$(6.9 \pm 1.4) \times 10^{-3}$		2249
$D^-_s \pi^+ \pi^+ \pi^-$		$(6.1 \pm 1.0) \times 10^{-3}$		2301
$D_{s1}(2536)^- \pi^+$, $D^-_{s1} \to D^-_s \pi^+ \pi^-$		$(2.5 \pm 0.8) \times 10^{-5}$		–
$D^\mp_s K^\pm$		$(2.27 \pm 0.19) \times 10^{-4}$		2293
$D^-_s K^+ \pi^+ \pi^-$		$(3.2 \pm 0.6) \times 10^{-4}$		2249
$D^+_s D^-_s$		$(4.4 \pm 0.5) \times 10^{-3}$		1824
$D^-_s D^+$		$(2.8 \pm 0.5) \times 10^{-4}$		1875
$D^+ D^-$		$(2.2 \pm 0.6) \times 10^{-4}$		1925
$D^0 \overline{D}^0$		$(1.9 \pm 0.5) \times 10^{-4}$		1930
$D^{*-}_s \pi^+$		$(2.0 \pm 0.5) \times 10^{-3}$		2265
$D^{*\mp}_s K^\pm$		$(1.33 \pm 0.35) \times 10^{-4}$		–
$D^{*-}_s \rho^+$		$(9.6 \pm 2.1) \times 10^{-3}$		2191
$D^{*+}_s D^-_s + D^{*-}_s D^+_s$		(1.39 ± 0.17) %		1742
$D^{*+}_s D^{*-}_s$		(1.44 ± 0.21) %	S=1.1	1655
$D^{(*)+}_s D^{(*)-}_s$		(4.5 ± 1.4) %		–
$\overline{D}^{*0} \overline{K}^0$		$(2.8 \pm 1.1) \times 10^{-4}$		2278
$\overline{D}^0 \overline{K}^0$		$(4.3 \pm 0.9) \times 10^{-4}$		2330
$\overline{D}^0 K^- \pi^+$		$(1.04 \pm 0.13) \times 10^{-3}$		2312
$\overline{D}^0 \overline{K}^*(892)^0$		$(4.4 \pm 0.6) \times 10^{-4}$		2264
$\overline{D}^0 \overline{K}^*(1410)$		$(3.9 \pm 3.5) \times 10^{-4}$		2117
$\overline{D}^0 \overline{K}^*_0(1430)$		$(3.0 \pm 0.7) \times 10^{-4}$		2113
$\overline{D}^0 \overline{K}^*_2(1430)$		$(1.1 \pm 0.4) \times 10^{-4}$		2112
$\overline{D}^0 \overline{K}^*(1680)$		$< 7.8 \times 10^{-5}$	CL=90%	1997
$\overline{D}^0 \overline{K}^*_0(1950)$		$< 1.1 \times 10^{-4}$	CL=90%	1890

$\overline{D}^0 \overline{K}_3^*(1780)$	$< 2.6 \times 10^{-5}$	CL=90%	1971
$\overline{D}^0 \overline{K}_4^*(2045)$	$< 3.1 \times 10^{-5}$	CL=90%	1835
$\overline{D}^0 K^- \pi^+$ (non-resonant)	$(2.1 \pm 0.8) \times 10^{-4}$		2312
$D_{s2}^*(2573)^- \pi^+$, $D_{s2}^* \to \overline{D}^0 K^-$	$(2.6 \pm 0.4) \times 10^{-4}$		–
$D_{s1}^*(2700)^- \pi^+$, $D_{s1}^* \to \overline{D}^0 K^-$	$(1.6 \pm 0.8) \times 10^{-5}$		–
$D_{s1}^*(2860)^- \pi^+$, $D_{s1}^* \to \overline{D}^0 K^-$	$(5 \pm 4) \times 10^{-5}$		–
$D_{s3}^*(2860)^- \pi^+$, $D_{s3}^* \to \overline{D}^0 K^-$	$(2.2 \pm 0.6) \times 10^{-5}$		–
$\overline{D}^0 K^+ K^-$	$(5.5 \pm 0.8) \times 10^{-5}$		2243
$\overline{D}^0 f_0(980)$	$< 3.1 \times 10^{-6}$	CL=90%	2242
$\overline{D}^0 \phi$	$(3.0 \pm 0.5) \times 10^{-5}$		2235
$\overline{D}^{*0} \phi$	$(3.7 \pm 0.6) \times 10^{-5}$		2178
$D^{*\mp} \pi^\pm$	$< 6.1 \times 10^{-6}$	CL=90%	–
$\eta_c \phi$	$(5.0 \pm 0.9) \times 10^{-4}$		1663
$\eta_c \pi^+ \pi^-$	$(1.8 \pm 0.7) \times 10^{-4}$		1840
$J/\psi(1S) \phi$	$(1.08 \pm 0.08) \times 10^{-3}$		1588
$J/\psi(1S) \phi\phi$	$(1.24^{+0.17}_{-0.19}) \times 10^{-5}$		764
$J/\psi(1S) \pi^0$	$< 1.2 \times 10^{-3}$	CL=90%	1787
$J/\psi(1S) \eta$	$(4.0 \pm 0.7) \times 10^{-4}$	S=1.4	1733
$J/\psi(1S) K_S^0$	$(1.88 \pm 0.15) \times 10^{-5}$		1743
$J/\psi(1S) \overline{K}^*(892)^0$	$(4.1 \pm 0.4) \times 10^{-5}$		1637
$J/\psi(1S) \eta'$	$(3.3 \pm 0.4) \times 10^{-4}$		1612
$J/\psi(1S) \pi^+ \pi^-$	$(2.09 \pm 0.23) \times 10^{-4}$	S=1.3	1775
$J/\psi(1S) f_0(500)$, $f_0 \to \pi^+ \pi^-$	$< 4 \times 10^{-6}$	CL=90%	–
$J/\psi(1S) \rho$, $\rho \to \pi^+ \pi^-$	$< 4 \times 10^{-6}$	CL=90%	–
$J/\psi(1S) f_0(980)$, $f_0 \to \pi^+ \pi^-$	$(1.28 \pm 0.18) \times 10^{-4}$	S=1.7	–
$J/\psi(1S) f_2(1270)$, $f_2 \to \pi^+ \pi^-$	$(1.1 \pm 0.4) \times 10^{-6}$		–
$J/\psi(1S) f_2(1270)_0$, $f_2 \to \pi^+ \pi^-$	$(7.5 \pm 1.8) \times 10^{-7}$		–
$J/\psi(1S) f_2(1270)_\parallel$, $f_2 \to \pi^+ \pi^-$	$(1.09 \pm 0.34) \times 10^{-6}$		–
$J/\psi(1S) f_2(1270)_\perp$, $f_2 \to \pi^+ \pi^-$	$(1.3 \pm 0.8) \times 10^{-6}$		–
$J/\psi(1S) f_0(1370)$, $f_0 \to \pi^+ \pi^-$	$(4.5^{+0.7}_{-4.0}) \times 10^{-5}$		–
$J/\psi(1S) f_0(1500)$, $f_0 \to \pi^+ \pi^-$	$(2.11^{+0.40}_{-0.29}) \times 10^{-5}$		–
$J/\psi(1S) f_2'(1525)_0$, $f_2' \to \pi^+ \pi^-$	$(1.07 \pm 0.24) \times 10^{-6}$		–
$J/\psi(1S) f_2'(1525)_\parallel$, $f_2' \to \pi^+ \pi^-$	$(1.3^{+2.7}_{-0.9}) \times 10^{-7}$		–
$J/\psi(1S) f_2'(1525)_\perp$, $f_2' \to \pi^+ \pi^-$	$(5 \pm 4) \times 10^{-7}$		–
$J/\psi(1S) f_0(1790)$, $f_0 \to \pi^+ \pi^-$	$(5.0^{+11.0}_{-1.1}) \times 10^{-6}$		–
$J/\psi(1S) \pi^+ \pi^-$ (nonresonant)	$(1.8^{+1.1}_{-0.4}) \times 10^{-5}$		1775
$J/\psi(1S) \overline{K}^0 \pi^+ \pi^-$	$< 4.4 \times 10^{-5}$	CL=90%	1675
$J/\psi(1S) K^+ K^-$	$(7.9 \pm 0.7) \times 10^{-4}$		1601
$J/\psi(1S) K^0 K^- \pi^+ +$ c.c.	$(9.2 \pm 1.3) \times 10^{-4}$		1538
$J/\psi(1S) \overline{K}^0 K^+ K^-$	$< 1.2 \times 10^{-5}$	CL=90%	1333

$J/\psi(1S) f_2'(1525)$		$(2.6 \pm 0.6) \times 10^{-4}$		1310
$J/\psi(1S) p\overline{p}$		$(3.6 \pm 0.4) \times 10^{-6}$		982
$J/\psi(1S)\gamma$	$<$	7.3×10^{-6}	CL=90%	1790
$J/\psi(1S)\pi^+\pi^-\pi^+\pi^-$		$(7.8 \pm 1.0) \times 10^{-5}$		1731
$J/\psi(1S) f_1(1285)$		$(7.2 \pm 1.4) \times 10^{-5}$		1460
$\psi(2S)\eta$		$(3.3 \pm 0.9) \times 10^{-4}$		1338
$\psi(2S)\eta'$		$(1.29 \pm 0.35) \times 10^{-4}$		1158
$\psi(2S)\pi^+\pi^-$		$(7.1 \pm 1.3) \times 10^{-5}$		1397
$\psi(2S)\phi$		$(5.4 \pm 0.6) \times 10^{-4}$		1120
$\psi(2S) K^-\pi^+$		$(3.1 \pm 0.4) \times 10^{-5}$		1310
$\psi(2S)\overline{K}^*(892)^0$		$(3.3 \pm 0.5) \times 10^{-5}$		1196
$\chi_{c1}\phi$		$(2.04 \pm 0.30) \times 10^{-4}$		1274
$\pi^+\pi^-$		$(7.0 \pm 1.0) \times 10^{-7}$		2680
$\pi^0\pi^0$	$<$	2.1×10^{-4}	CL=90%	2680
$\eta\pi^0$	$<$	1.0×10^{-3}	CL=90%	2654
$\eta\eta$	$<$	1.5×10^{-3}	CL=90%	2627
$\rho^0\rho^0$	$<$	3.20×10^{-4}	CL=90%	2569
$\eta'\eta'$		$(3.3 \pm 0.7) \times 10^{-5}$		2507
$\eta'\phi$	$<$	8.2×10^{-7}	CL=90%	2495
$\phi f_0(980)$, $f_0(980) \to \pi^+\pi^-$		$(1.12 \pm 0.21) \times 10^{-6}$		–
$\phi f_2(1270)$, $f_2(1270) \to \pi^+\pi^-$		$(6.1 ^{+1.8}_{-1.5}) \times 10^{-7}$		–
$\phi\rho^0$		$(2.7 \pm 0.8) \times 10^{-7}$		2526
$\phi\pi^+\pi^-$		$(3.5 \pm 0.5) \times 10^{-6}$		2579
$\phi\phi$		$(1.87 \pm 0.15) \times 10^{-5}$		2482
$\phi\phi\phi$		$(2.2 \pm 0.7) \times 10^{-6}$		2165
$\pi^+ K^-$		$(5.8 \pm 0.7) \times 10^{-6}$		2659
$K^+ K^-$		$(2.66 \pm 0.22) \times 10^{-5}$		2638
$K^0\overline{K}^0$		$(2.0 \pm 0.6) \times 10^{-5}$		2637
$K^0\pi^+\pi^-$		$(9.5 \pm 2.1) \times 10^{-6}$		2653
$K^0 K^\pm\pi^\mp$		$(8.4 \pm 0.9) \times 10^{-5}$		2622
$K^*(892)^-\pi^+$		$(2.9 \pm 1.1) \times 10^{-6}$		2607
$K^*(892)^\pm K^\mp$		$(1.9 \pm 0.5) \times 10^{-5}$		2585
$K_0^*(1430)^\pm K^\mp$		$(3.1 \pm 2.5) \times 10^{-5}$		–
$K_2^*(1430)^\pm K^\mp$		$(1.0 \pm 1.7) \times 10^{-5}$		–
$K^*(892)^0\overline{K}^0$ + c.c.		$(2.0 \pm 0.6) \times 10^{-5}$		2585
$K_0^*(1430)\overline{K}^0$ + c.c.		$(3.3 \pm 1.0) \times 10^{-5}$		2468
$K_2^*(1430)^0\overline{K}^0$ + c.c.		$(1.7 \pm 2.2) \times 10^{-5}$		2467
$K_S^0\overline{K}^*(892)^0$ + c.c.		$(1.6 \pm 0.4) \times 10^{-5}$		2585
$K^0 K^+ K^-$		$(1.3 \pm 0.6) \times 10^{-6}$		2568
$\overline{K}^*(892)^0\rho^0$	$<$	7.67×10^{-4}	CL=90%	2550
$\overline{K}^*(892)^0 K^*(892)^0$		$(1.11 \pm 0.27) \times 10^{-5}$		2531
$\phi K^*(892)^0$		$(1.14 \pm 0.30) \times 10^{-6}$		2507
$p\overline{p}$	$<$	1.5×10^{-8}	CL=90%	2514
$p\overline{p} K^+ K^-$		$(4.5 \pm 0.5) \times 10^{-6}$		2231
$p\overline{p} K^+\pi^-$		$(1.39 \pm 0.26) \times 10^{-6}$		2355
$p\overline{p}\pi^+\pi^-$		$(4.3 \pm 2.0) \times 10^{-7}$		2454
$p\overline{\Lambda} K^-$ + c.c.		$(5.5 \pm 1.0) \times 10^{-6}$		2358
$\Lambda_c^-\Lambda\pi^+$		$(3.6 \pm 1.6) \times 10^{-4}$		1979
$\Lambda_c^-\Lambda_c^+$	$<$	8.0×10^{-5}	CL=95%	1405

Lepton Family number (*LF*) violating modes or $\Delta B = 1$ weak neutral current (*B1*) modes

$\gamma\gamma$	*B1*		$< 3.1 \times 10^{-6}$	CL=90%	2683
$\phi\gamma$	*B1*		$(3.4 \pm 0.4) \times 10^{-5}$		2587
$\mu^+\mu^-$	*B1*		$(3.0 \pm 0.4) \times 10^{-9}$		2681
e^+e^-	*B1*		$< 2.8 \times 10^{-7}$	CL=90%	2683
$\tau^+\tau^-$	*B1*		$< 6.8 \times 10^{-3}$	CL=95%	2011
$\mu^+\mu^-\mu^+\mu^-$	*B1*		$< 2.5 \times 10^{-9}$	CL=95%	2673
SP, $S \to \mu^+\mu^-$, $P \to \mu^+\mu^-$	*B1*	[aaaa]	$< 2.2 \times 10^{-9}$	CL=95%	–
$\phi(1020)\mu^+\mu^-$	*B1*		$(8.2 \pm 1.2) \times 10^{-7}$		2582
$\overline{K}^*(892)^0\mu^+\mu^-$			$(2.9 \pm 1.1) \times 10^{-8}$		2605
$\pi^+\pi^-\mu^+\mu^-$	*B1*		$(8.4 \pm 1.7) \times 10^{-8}$		2670
$\phi\nu\overline{\nu}$	*B1*		$< 5.4 \times 10^{-3}$	CL=90%	2587
$e^\pm\mu^\mp$	*LF*	[bb]	$< 5.4 \times 10^{-9}$	CL=90%	2682
$\mu^\pm\tau^\mp$			$< 4.2 \times 10^{-5}$	CL=95%	2388

B_s^*

$I(J^P) = 0(1^-)$

I, J, P need confirmation. Quantum numbers shown are quark-model predictions.

Mass $m = 5415.4^{+1.8}_{-1.5}$ MeV (S = 2.9)

$m_{B_s^*} - m_{B_s} = 48.6^{+1.8}_{-1.5}$ MeV (S = 2.9)

$B_{s1}(5830)^0$

$I(J^P) = 0(1^+)$

I, J, P need confirmation.

Mass $m = 5828.70 \pm 0.20$ MeV

$m_{B_{s1}^0} - m_{B^{*+}} = 504.00 \pm 0.17$ MeV

Full width $\Gamma = 0.5 \pm 0.4$ MeV

$B_{s2}^*(5840)^0$

$I(J^P) = 0(2^+)$

I, J, P need confirmation.

Mass $m = 5839.86 \pm 0.12$ MeV

$m_{B_{s2}^{*0}} - m_{B^+} = 560.52 \pm 0.14$ MeV

Full width $\Gamma = 1.49 \pm 0.27$ MeV

$B_{s2}^*(5840)^0$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
B^+K^-	**DEFINED AS 1**	252
$B^{*+}K^-$	0.093 ± 0.018	141
$B^0K_S^0$	0.43 ± 0.11	245
$B^{*0}K_S^0$	0.04 ± 0.04	–

BOTTOM, CHARMED MESONS ($B = C = \pm1$)

$B_c^+ = c\overline{b}$, $B_c^- = \overline{c}b$, similarly for B_c^*'s

B_c^+

$I(J^P) = 0(0^-)$
I, J, P need confirmation.

Quantum numbers shown are quark-model predictions.

Mass $m = 6274.9 \pm 0.8$ MeV
Mean life $\tau = (0.510 \pm 0.009) \times 10^{-12}$ s

B_c^- modes are charge conjugates of the modes below.

B_c^+ DECAY MODES × B($\overline{b} \to B_c$)	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
The following quantities are not pure branching ratios; rather the fraction $\Gamma_i/\Gamma \times$ B($\overline{b} \to B_c$).			
$J/\psi(1S)\ell^+\nu_\ell$ anything	$(8.1 \pm 1.2) \times 10^{-5}$		–
$J/\psi(1S)a_1(1260)$	$< 1.2 \times 10^{-3}$	90%	2169
$\chi_c^0\pi^+$	$(2.4 {}^{+0.9}_{-0.8}) \times 10^{-5}$		2205
D^0K^+	$(3.8 {}^{+1.2}_{-1.1}) \times 10^{-7}$		2837
$D^0\pi^+$	$< 1.6 \times 10^{-7}$	95%	2858
$D^{*0}\pi^+$	$< 4 \times 10^{-7}$	95%	2815
$D^{*0}K^+$	$< 4 \times 10^{-7}$	95%	2793
$D_s^+\overline{D}^0$	$< 1.4 \times 10^{-7}$	90%	2484
$D_s^+D^0$	$< 6 \times 10^{-8}$	90%	2484
$D^+\overline{D}^0$	$< 3.0 \times 10^{-6}$	90%	2521
D^+D^0	$< 1.9 \times 10^{-6}$	90%	2521
$D^*(2010)^+\overline{D}^0$	$< 6.2 \times 10^{-3}$	90%	2467
$D_s^{*+}\overline{D}^*(2007)^0$	$< 1.7 \times 10^{-6}$	90%	2366
$D_s^{*+}D^*(2007)^0$	$< 3.1 \times 10^{-6}$	90%	2366
$D^*(2010)^+\overline{D}^*(2007)^0$	$< 1.0 \times 10^{-4}$	90%	2410
$D^*(2010)^+D^*(2007)^0$	$< 2.0 \times 10^{-5}$	90%	2410
D^+K^{*0}	$< 0.20 \times 10^{-6}$	90%	2783
$D^+\overline{K}^{*0}$	$< 0.16 \times 10^{-6}$	90%	2783
$D_s^+K^{*0}$	$< 0.28 \times 10^{-6}$	90%	2751
$D_s^+\overline{K}^{*0}$	$< 0.4 \times 10^{-6}$	90%	2751
$D_s^+\phi$	$< 0.32 \times 10^{-6}$	90%	2727
K^+K^0	$< 4.6 \times 10^{-7}$	90%	3098
$B_s^0\pi^+$ / B($\overline{b} \to B_s$)	$(2.37{}^{+0.37}_{-0.35}) \times 10^{-3}$		–

See Particle Listings for 14 decay modes that have been seen / not seen.

$c\overline{c}$ MESONS (including possibly non-$q\overline{q}$ states)

$\eta_c(1S)$

$I^G(J^{PC}) = 0^+(0^{-+})$

Mass $m = 2983.9 \pm 0.5$ MeV (S = 1.3)
Full width $\Gamma = 32.0 \pm 0.7$ MeV

$\eta_c(1S)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
Decays involving hadronic resonances			
$\eta'(958)\pi\pi$	(4.1 ± 1.7) %		1323
$\rho\rho$	(1.8 ± 0.5) %		1275
$K^*(892)^0 K^- \pi^+ +$ c.c.	(2.0 ± 0.7) %		1278
$K^*(892)\overline{K}^*(892)$	$(7.0 \pm 1.3) \times 10^{-3}$		1196
$K^*(892)^0 \overline{K}^*(892)^0 \pi^+\pi^-$	(1.1 ± 0.5) %		1073
$\phi K^+ K^-$	$(2.9 \pm 1.4) \times 10^{-3}$		1104
$\phi\phi$	$(1.77 \pm 0.19) \times 10^{-3}$		1089
$\phi 2(\pi^+\pi^-)$	$< 4 \times 10^{-3}$	90%	1251
$a_0(980)\pi$	< 2 %	90%	1327
$a_2(1320)\pi$	< 2 %	90%	1197
$K^*(892)\overline{K} +$ c.c.	< 1.28 %	90%	1310
$f_2(1270)\eta$	< 1.1 %	90%	1145
$\omega\omega$	$(2.9 \pm 0.8) \times 10^{-3}$		1270
$\omega\phi$	$< 2.5 \times 10^{-4}$	90%	1185
$f_2(1270) f_2(1270)$	$(9.8 \pm 2.5) \times 10^{-3}$		774
$f_2(1270) f'_2(1525)$	$(9.7 \pm 3.2) \times 10^{-3}$		524
Decays into stable hadrons			
$K\overline{K}\pi$	(7.3 ± 0.4) %		1381
$K\overline{K}\eta$	(1.36 ± 0.15) %		1265
$\eta\pi^+\pi^-$	(1.7 ± 0.5) %		1428
$\eta 2(\pi^+\pi^-)$	(4.4 ± 1.3) %		1386
$K^+K^-\pi^+\pi^-$	$(6.9 \pm 1.0) \times 10^{-3}$		1345
$K^+K^-\pi^+\pi^-\pi^0$	(3.5 ± 0.6) %		1304
$K^0 K^- \pi^+\pi^-\pi^+ +$c.c.	(5.6 ± 1.5) %		–
$K^+K^- 2(\pi^+\pi^-)$	$(7.5 \pm 2.4) \times 10^{-3}$		1254
$2(K^+K^-)$	$(1.46 \pm 0.30) \times 10^{-3}$		1056
$\pi^+\pi^-\pi^0$	$< 5 \times 10^{-4}$	90%	1476
$\pi^+\pi^-\pi^0\pi^0$	(4.7 ± 1.0) %		1460
$2(\pi^+\pi^-)$	$(9.7 \pm 1.2) \times 10^{-3}$		1459
$2(\pi^+\pi^-\pi^0)$	(16.1 ± 2.0) %		1409
$3(\pi^+\pi^-)$	(1.8 ± 0.4) %		1407
$p\overline{p}$	$(1.45 \pm 0.14) \times 10^{-3}$		1160
$p\overline{p}\pi^0$	$(3.6 \pm 1.3) \times 10^{-3}$		1101
$\Lambda\overline{\Lambda}$	$(1.07 \pm 0.24) \times 10^{-3}$		991
$K^+\overline{p}\Lambda +$ c.c.	$(2.6 \pm 0.4) \times 10^{-3}$		772
$\overline{\Lambda}(1520)\Lambda +$ c.c.	$(3.1 \pm 1.4) \times 10^{-3}$		694
$\Sigma^+\overline{\Sigma}^-$	$(2.1 \pm 0.6) \times 10^{-3}$		901
$\Xi^-\overline{\Xi}^+$	$(9.0 \pm 2.6) \times 10^{-4}$		692
$\pi^+\pi^- p\overline{p}$	$(5.3 \pm 1.8) \times 10^{-3}$		1027
Radiative decays			
$\gamma\gamma$	$(1.58 \pm 0.11) \times 10^{-4}$		1492

Charge conjugation (C), Parity (P), Lepton family number (LF) violating modes

$\pi^+\pi^-$	P,CP	$< 1.1 \times 10^{-4}$	90%	1485
$\pi^0\pi^0$	P,CP	$< 4 \times 10^{-5}$	90%	1486
K^+K^-	P,CP	$< 6 \times 10^{-4}$	90%	1408
$K^0_S K^0_S$	P,CP	$< 3.1 \times 10^{-4}$	90%	1407

See Particle Listings for 10 decay modes that have been seen / not seen.

$J/\psi(1S)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 3096.900 \pm 0.006$ MeV

Full width $\Gamma = 92.9 \pm 2.8$ keV (S = 1.1)

$\Gamma_{ee} = 5.53 \pm 0.10$ keV

$\Gamma_{ee} < 5.4$ eV, CL = 90%

$J/\psi(1S)$ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
hadrons		(87.7 ± 0.5) %		–
virtual$\gamma \to$ hadrons		(13.50 ± 0.30) %		–
ggg		(64.1 ± 1.0) %		–
γgg		(8.8 ± 1.1) %		–
e^+e^-		(5.971 ± 0.032) %		1548
$e^+e^-\gamma$	[kkaa]	$(8.8 \pm 1.4) \times 10^{-3}$		1548
$\mu^+\mu^-$		(5.961 ± 0.033) %		1545

Decays involving hadronic resonances

$\rho\pi$		(1.69 ± 0.15) %	S=2.4	1448
$\rho^0\pi^0$		$(5.6 \pm 0.7) \times 10^{-3}$		1448
$\rho(770)^\mp K^\pm K^0_S$		$(1.9 \pm 0.4) \times 10^{-3}$		–
$\rho(1450)\pi \to \pi^+\pi^-\pi^0$		$(2.3 \pm 0.7) \times 10^{-3}$		–
$\rho(1450)^\pm\pi^\mp \to K^0_S K^\pm\pi^\mp$		$(3.5 \pm 0.6) \times 10^{-4}$		–
$\rho(1450)^0\pi^0 \to K^+K^-\pi^0$		$(2.7 \pm 0.6) \times 10^{-4}$		–
$\rho(1450)\eta'(958) \to \pi^+\pi^-\eta'(958)$		$(3.3 \pm 0.7) \times 10^{-6}$		–
$\rho(1700)\pi \to \pi^+\pi^-\pi^0$		$(1.7 \pm 1.1) \times 10^{-4}$		–
$\rho(2150)\pi \to \pi^+\pi^-\pi^0$		$(8 \pm 40) \times 10^{-6}$		–
$a_2(1320)\rho$		(1.09 ± 0.22) %		1124
$\omega\pi^+\pi^+\pi^-\pi^-$		$(8.5 \pm 3.4) \times 10^{-3}$		1392
$\omega\pi^+\pi^-\pi^0$		$(4.0 \pm 0.7) \times 10^{-3}$		1418
$\omega\pi^+\pi^-$		$(7.2 \pm 1.0) \times 10^{-3}$		1435
$\omega f_2(1270)$		$(4.3 \pm 0.6) \times 10^{-3}$		1142
$K^*(892)^0\overline{K}^*(892)^0$		$(2.3 \pm 0.6) \times 10^{-4}$		1266
$K^*(892)^\pm K^*(892)^\mp$		$(1.00 {}^{+0.22}_{-0.40}) \times 10^{-3}$		1266
$K^*(892)^\pm K^*(700)^\mp$		$(1.1 {}^{+1.0}_{-0.6}) \times 10^{-3}$		–
$K^0_S\pi^- K^*(892)^+ +$ c.c.		$(2.0 \pm 0.5) \times 10^{-3}$		1342
$K^0_S\pi^- K^*(892)^+ +$ c.c. $\to K^0_S K^0_S\pi^+\pi^-$		$(6.7 \pm 2.2) \times 10^{-4}$		–
$K^0_S K^*(892)^0 \to \gamma K^0_S K^0_S$		$(6.3 {}^{+0.6}_{-0.5}) \times 10^{-6}$		–
$K^*_2(1430)^+K^- +$ c.c. $\to K^+K^-\pi^0$		$(2.69 {}^{+0.25}_{-0.19}) \times 10^{-4}$		–
$K^*_2(1980)^+K^- +$ c.c. $\to K^+K^-\pi^0$		$(1.10 {}^{+0.60}_{-0.14}) \times 10^{-5}$		–

$K_4^*(2045)^+ K^- +$ c.c. $\to$ $K^+ K^- \pi^0$		$(6.2 \ {}^{+\ 2.9}_{-\ 1.6}) \times 10^{-6}$		–
$\eta K^*(892)^0 \overline{K}^*(892)^0$		$(1.15 \pm 0.26) \times 10^{-3}$		1003
$\eta' K^{*\pm} K^{\mp}$		$(1.48 \pm 0.13) \times 10^{-3}$		–
$\eta' K^{*0} \overline{K}^0 +$ c.c.		$(1.66 \pm 0.21) \times 10^{-3}$		1000
$\eta' h_1(1415) \to \eta' K^* \overline{K} +$ c.c.		$(2.16 \pm 0.31) \times 10^{-4}$		–
$\eta' h_1(1415) \to \eta' K^{*\pm} K^{\mp}$		$(1.51 \pm 0.23) \times 10^{-4}$		–
$K^*(1410) \overline{K}$ +c.c $\to$ $K^\pm K^\mp \pi^0$		$(7 \pm 4) \times 10^{-5}$		–
$K^*(1410) \overline{K} +$ c.c. $\to$ $K_S^0 K^\pm \pi^\mp$		$(8 \pm 6) \times 10^{-5}$		–
$K_2^*(1430) \overline{K}$ +c.c. $\to$ $K^\pm K^\mp \pi^0$		$(1.0 \pm 0.5) \times 10^{-4}$		–
$K_2^*(1430) \overline{K} +$ c.c. $\to$ $K_S^0 K^\pm \pi^\mp$		$(4.0 \pm 1.0) \times 10^{-4}$		–
$K^*(892)^0 \overline{K}_2^*(1430)^0 +$ c.c.		$(4.66 \pm 0.31) \times 10^{-3}$		1011
$K^*(892)^+ K_2^*(1430)^- +$ c.c.		$(3.4 \pm 2.9) \times 10^{-3}$		1011
$K^*(892)^+ K_2^*(1430)^- +$ c.c. $\to$ $K^*(892)^+ K_S^0 \pi^- +$ c.c.		$(4 \pm 4) \times 10^{-4}$		–
$K^*(892)^0 \overline{K}_2(1770)^0 +$ c.c. $\to$ $K^*(892)^0 K^- \pi^+ +$ c.c.		$(6.9 \pm 0.9) \times 10^{-4}$		–
$\omega K^*(892) \overline{K} +$ c.c.		$(6.1 \pm 0.9) \times 10^{-3}$		1097
$\overline{K} K^*(892)$+c.c. $\to$ $K_S^0 K^\pm \pi^\mp$		$(5.0 \pm 0.5) \times 10^{-3}$		–
$K^+ K^*(892)^- +$ c.c.		$(6.0 \ {}^{+\ 0.8}_{-\ 1.0}) \times 10^{-3}$	S=2.9	1373
$K^+ K^*(892)^- +$ c.c. $\to$ $K^+ K^- \pi^0$		$(2.69 \ {}^{+\ 0.13}_{-\ 0.20}) \times 10^{-3}$		–
$K^+ K^*(892)^- +$ c.c. $\to$ $K^0 K^\pm \pi^\mp +$ c.c.		$(3.0 \pm 0.4) \times 10^{-3}$		–
$K^0 \overline{K}^*(892)^0 +$ c.c.		$(4.2 \pm 0.4) \times 10^{-3}$		1373
$K^0 \overline{K}^*(892)^0 +$ c.c. $\to$ $K^0 K^\pm \pi^\mp +$ c.c.		$(3.2 \pm 0.4) \times 10^{-3}$		–
$K_1(1400)^\pm K^\mp$		$(3.8 \pm 1.4) \times 10^{-3}$		1170
$\overline{K}^*(892)^0 K^+ \pi^- +$ c.c.		$(7.7 \pm 1.6) \times 10^{-3}$		1343
$K^*(892)^\pm K^\mp \pi^0$		$(4.1 \pm 1.3) \times 10^{-3}$		1344
$K^*(892)^0 K_S^0 \pi^0$		$(6 \pm 4) \times 10^{-4}$		1343
$\omega \pi^0 \pi^0$		$(3.4 \pm 0.8) \times 10^{-3}$		1436
$\omega \pi^0 \eta$		$(3.4 \pm 1.7) \times 10^{-4}$		1363
$b_1(1235)^\pm \pi^\mp$	[*bb*]	$(3.0 \pm 0.5) \times 10^{-3}$		1300
$\omega K^\pm K_S^0 \pi^\mp$	[*bb*]	$(3.4 \pm 0.5) \times 10^{-3}$		1210
$b_1(1235)^0 \pi^0$		$(2.3 \pm 0.6) \times 10^{-3}$		1300
$\eta K^\pm K_S^0 \pi^\mp$	[*bb*]	$(2.2 \pm 0.4) \times 10^{-3}$		1278
$\phi K^*(892) \overline{K} +$ c.c.		$(2.18 \pm 0.23) \times 10^{-3}$		969
$\omega K \overline{K}$		$(1.9 \pm 0.4) \times 10^{-3}$		1268
$\omega f_0(1710) \to \omega K \overline{K}$		$(4.8 \pm 1.1) \times 10^{-4}$		878
$\phi 2(\pi^+ \pi^-)$		$(1.60 \pm 0.32) \times 10^{-3}$		1318
$\Delta(1232)^{++} \overline{p} \pi^-$		$(1.6 \pm 0.5) \times 10^{-3}$		1030
$\omega \eta$		$(1.74 \pm 0.20) \times 10^{-3}$	S=1.6	1394
$\omega \eta' \pi^+ \pi^-$		$(1.12 \pm 0.13) \times 10^{-3}$		1173
$\phi K \overline{K}$		$(1.77 \pm 0.16) \times 10^{-3}$	S=1.3	1179
$\phi K_S^0 K_S^0$		$(5.9 \pm 1.5) \times 10^{-4}$		1176
$\phi f_0(1710) \to \phi K \overline{K}$		$(3.6 \pm 0.6) \times 10^{-4}$		875
$\phi K^+ K^-$		$(8.3 \pm 1.2) \times 10^{-4}$		1179
$\phi f_2(1270)$		$(3.2 \pm 0.6) \times 10^{-4}$		1036

$\Delta(1232)^{++}\overline{\Delta}(1232)^{--}$		$(1.10 \pm 0.29) \times 10^{-3}$		938
$\Sigma(1385)^{-}\overline{\Sigma}(1385)^{+}$ (or c.c.)	[*bb*]	$(1.16 \pm 0.05) \times 10^{-3}$		697
$\Sigma(1385)^{0}\overline{\Sigma}(1385)^{0}$		$(1.07 \pm 0.08) \times 10^{-3}$		697
$K^{+}K^{-}f_2'(1525)$		$(1.05 \pm 0.35) \times 10^{-3}$		897
$\phi f_2'(1525)$		$(8 \pm 4) \times 10^{-4}$	S=2.7	877
$\phi\pi^{+}\pi^{-}$		$(9.4 \pm 1.5) \times 10^{-4}$	S=1.7	1365
$\phi\pi^{0}\pi^{0}$		$(5.0 \pm 1.0) \times 10^{-4}$		1366
$\phi K^{\pm}K^{0}_{S}\pi^{\mp}$	[*bb*]	$(7.2 \pm 0.8) \times 10^{-4}$		1114
$\omega f_1(1420)$		$(6.8 \pm 2.4) \times 10^{-4}$		1062
$\phi\eta$		$(7.4 \pm 0.8) \times 10^{-4}$	S=1.5	1320
$\Xi^{0}\overline{\Xi}^{0}$		$(1.17 \pm 0.04) \times 10^{-3}$		818
$\Xi(1530)^{-}\overline{\Xi}^{+}$ + c.c.		$(3.18 \pm 0.08) \times 10^{-4}$		600
$pK^{-}\overline{\Sigma}(1385)^{0}$		$(5.1 \pm 3.2) \times 10^{-4}$		646
$\omega\pi^{0}$		$(4.5 \pm 0.5) \times 10^{-4}$	S=1.4	1446
$\omega\pi^{0} \to \pi^{+}\pi^{-}\pi^{0}$		$(1.7 \pm 0.8) \times 10^{-5}$		–
$\phi\eta'(958)$		$(4.6 \pm 0.5) \times 10^{-4}$	S=2.2	1192
$\phi f_0(980)$		$(3.2 \pm 0.9) \times 10^{-4}$	S=1.9	1178
$\phi f_0(980) \to \phi\pi^{+}\pi^{-}$		$(2.59 \pm 0.34) \times 10^{-4}$		–
$\phi f_0(980) \to \phi\pi^{0}\pi^{0}$		$(1.8 \pm 0.5) \times 10^{-4}$		–
$\phi\eta\eta'$		$(2.32 \pm 0.17) \times 10^{-4}$		885
$\phi\pi^{0}f_0(980) \to \phi\pi^{0}\pi^{+}\pi^{-}$		$(4.5 \pm 1.0) \times 10^{-6}$		–
$\phi\pi^{0}f_0(980) \to \phi\pi^{0}p^{0}\pi^{0}$		$(1.7 \pm 0.6) \times 10^{-6}$		1045
$\eta\phi f_0(980) \to \eta\phi\pi^{+}\pi^{-}$		$(3.2 \pm 1.0) \times 10^{-4}$		–
$\phi a_0(980)^{0} \to \phi\eta\pi^{0}$		$(4.4 \pm 1.4) \times 10^{-6}$		–
$\Xi(1530)^{0}\overline{\Xi}^{0}$		$(3.2 \pm 1.4) \times 10^{-4}$		608
$\Sigma(1385)^{-}\overline{\Sigma}^{+}$ (or c.c.)	[*bb*]	$(3.1 \pm 0.5) \times 10^{-4}$		855
$\phi f_1(1285)$		$(2.6 \pm 0.5) \times 10^{-4}$		1032
$\phi f_1(1285) \to \phi\pi^{0}f_0(980) \to \phi\pi^{0}\pi^{+}\pi^{-}$		$(9.4 \pm 2.8) \times 10^{-7}$		952
$\phi f_1(1285) \to \phi\pi^{0}f_0(980) \to \phi\pi^{0}\pi^{0}\pi^{0}$		$(2.1 \pm 2.2) \times 10^{-7}$		955
$\eta\pi^{+}\pi^{-}$		$(3.8 \pm 0.7) \times 10^{-4}$		1487
$\eta\rho$		$(1.93 \pm 0.23) \times 10^{-4}$		1396
$\omega\eta'(958)$		$(1.89 \pm 0.18) \times 10^{-4}$		1279
$\omega f_0(980)$		$(1.4 \pm 0.5) \times 10^{-4}$		1267
$\rho\eta'(958)$		$(8.1 \pm 0.8) \times 10^{-5}$	S=1.6	1281
$a_2(1320)^{\pm}\pi^{\mp}$	[*bb*]	$< 4.3 \times 10^{-3}$	CL=90%	1264
$K\overline{K}{}^{*}_{2}(1430)$ + c.c.		$< 4.0 \times 10^{-3}$	CL=90%	1158
$K_1(1270)^{\pm}K^{\mp}$		$< 3.0 \times 10^{-3}$	CL=90%	1240
$K_1(1270)K^{0}_{S} \to \gamma K^{0}_{S}K^{0}_{S}$		$(8.5 \pm 2.5) \times 10^{-7}$		–
$K^{0}_{S}\pi^{-}K^{*}_{2}(1430)^{+}$ + c.c.		$(3.6 \pm 1.8) \times 10^{-3}$		1116
$K^{*}_{2}(1430)^{0}\overline{K}{}^{*}_{2}(1430)^{0}$		$< 2.9 \times 10^{-3}$	CL=90%	601
$\phi\pi^{0}$		3×10^{-6} or 1×10^{-7}		1377
$\phi\eta(1405) \to \phi\eta\pi^{+}\pi^{-}$		$(2.0 \pm 1.0) \times 10^{-5}$		946
$\omega f_2'(1525)$		$< 2.2 \times 10^{-4}$	CL=90%	1007
$\omega X(1835) \to \omega p\overline{p}$		$< 3.9 \times 10^{-6}$	CL=95%	–
$\omega X(1835),\ X \to \eta'\pi^{+}\pi^{-}$		$< 6.2 \times 10^{-5}$		–
$\phi X(1835) \to \phi p\overline{p}$		$< 2.1 \times 10^{-7}$	CL=90%	–
$\phi X(1835) \to \phi\eta\pi^{+}\pi^{-}$		$< 2.8 \times 10^{-4}$	CL=90%	578
$\phi X(1870) \to \phi\eta\pi^{+}\pi^{-}$		$< 6.13 \times 10^{-5}$	CL=90%	–
$\eta\phi(2170) \to \eta\phi f_0(980) \to \eta\phi\pi^{+}\pi^{-}$		$(1.2 \pm 0.4) \times 10^{-4}$		628
$\eta\phi(2170) \to \eta K^{*}(892)^{0}\overline{K}{}^{*}(892)^{0}$		$< 2.52 \times 10^{-4}$	CL=90%	–

$\Sigma(1385)^0\overline{\Lambda}$ + c.c.		$< 8.2 \times 10^{-6}$	CL=90%	912
$\Delta(1232)^+\overline{p}$		$< 1 \times 10^{-4}$	CL=90%	1100
$\Lambda(1520)\overline{\Lambda}$ + c.c. $\to \gamma\Lambda\overline{\Lambda}$		$< 4.1 \times 10^{-6}$	CL=90%	–
$\overline{\Lambda}(1520)\Lambda$ + c.c.		$< 1.80 \times 10^{-3}$	CL=90%	807
$\Theta(1540)\overline{\Theta}(1540) \to K^0_S p K^- \overline{n}$ + c.c.		$< 1.1 \times 10^{-5}$	CL=90%	–
$\Theta(1540)K^-\overline{n} \to K^0_S p K^- \overline{n}$		$< 2.1 \times 10^{-5}$	CL=90%	–
$\Theta(1540)K^0_S\overline{p} \to K^0_S \overline{p} K^+ n$		$< 1.6 \times 10^{-5}$	CL=90%	–
$\overline{\Theta}(1540)K^+ n \to K^0_S \overline{p} K^+ n$		$< 5.6 \times 10^{-5}$	CL=90%	–
$\overline{\Theta}(1540)K^0_S p \to K^0_S p K^- \overline{n}$		$< 1.1 \times 10^{-5}$	CL=90%	–
Decays into stable hadrons				
$2(\pi^+\pi^-)\pi^0$		(3.73 ± 0.32) %	S=1.4	1496
$3(\pi^+\pi^-)\pi^0$		(2.9 ± 0.6) %		1433
$\pi^+\pi^-\pi^0$		(2.10 ± 0.08) %	S=1.6	1533
$\pi^+\pi^-\pi^0\pi^0\pi^0$		(2.71 ± 0.29) %		1497
$\rho^\pm\pi^\mp\pi^0\pi^0$		(1.41 ± 0.22) %		1421
$\rho^+\rho^-\pi^0$		$(6.0 \pm 1.1) \times 10^{-3}$		1298
$\pi^+\pi^-\pi^0K^+K^-$		(1.20 ± 0.30) %		1368
$4(\pi^+\pi^-)\pi^0$		$(9.0 \pm 3.0) \times 10^{-3}$		1345
$\pi^+\pi^-K^+K^-$		$(6.84 \pm 0.32) \times 10^{-3}$		1407
$\pi^+\pi^-K^0_S K^0_L$		$(3.8 \pm 0.6) \times 10^{-3}$		1406
$\pi^+\pi^-K^0_S K^0_S$		$(1.68 \pm 0.19) \times 10^{-3}$		1406
$\pi^\pm\pi^0K^\mp K^0_S$		$(5.7 \pm 0.5) \times 10^{-3}$		1408
$K^+K^-K^0_S K^0_S$		$(4.1 \pm 0.8) \times 10^{-4}$		1127
$\pi^+\pi^-K^+K^-\eta$		$(4.7 \pm 0.7) \times 10^{-3}$		1221
$\pi^0\pi^0K^+K^-$		$(2.12 \pm 0.23) \times 10^{-3}$		1410
$\pi^0\pi^0K^0_S K^0_L$		$(1.9 \pm 0.4) \times 10^{-3}$		1408
$K\overline{K}\pi$		$(6.1 \pm 1.0) \times 10^{-3}$		1442
$K^+K^-\pi^0$		$(2.88 \pm 0.12) \times 10^{-3}$		1442
$K^0_S K^\pm\pi^\mp$		$(5.6 \pm 0.5) \times 10^{-3}$		1440
$K^0_S K^0_L\pi^0$		$(2.06 \pm 0.27) \times 10^{-3}$		1440
$K^*(892)^0\overline{K}^0$ + c.c. $\to K^0_S K^0_L \pi^0$		$(1.21 \pm 0.18) \times 10^{-3}$		–
$K^*_2(1430)^0\overline{K}^0$ + c.c. $\to K^0_S K^0_L \pi^0$		$(4.3 \pm 1.3) \times 10^{-4}$		–
$K^0_S K^0_L\eta$		$(1.44 \pm 0.34) \times 10^{-3}$		1328
$2(\pi^+\pi^-)$		$(3.57 \pm 0.30) \times 10^{-3}$		1517
$3(\pi^+\pi^-)$		$(4.3 \pm 0.4) \times 10^{-3}$		1466
$2(\pi^+\pi^-\pi^0)$		(1.61 ± 0.21) %		1468
$2(\pi^+\pi^-)\eta$		$(2.26 \pm 0.28) \times 10^{-3}$		1446
$3(\pi^+\pi^-)\eta$		$(7.2 \pm 1.5) \times 10^{-4}$		1379
$\pi^+\pi^-\pi^0\pi^0\eta$		$(2.3 \pm 0.5) \times 10^{-3}$		1448
$\rho^\pm\pi^\mp\pi^0\eta$		$(1.9 \pm 0.8) \times 10^{-3}$		1326
$p\overline{p}$		$(2.121 \pm 0.029) \times 10^{-3}$		1232
$p\overline{p}\pi^0$		$(1.19 \pm 0.08) \times 10^{-3}$	S=1.1	1176
$p\overline{p}\pi^+\pi^-$		$(6.0 \pm 0.5) \times 10^{-3}$	S=1.3	1107
$p\overline{p}\pi^+\pi^-\pi^0$	[llaa]	$(2.3 \pm 0.9) \times 10^{-3}$	S=1.9	1033
$p\overline{p}\eta$		$(2.00 \pm 0.12) \times 10^{-3}$		948
$p\overline{p}\rho$		$< 3.1 \times 10^{-4}$	CL=90%	774
$p\overline{p}\omega$		$(9.8 \pm 1.0) \times 10^{-4}$	S=1.3	768
$p\overline{p}\eta'(958)$		$(1.29 \pm 0.14) \times 10^{-4}$	S=2.0	596
$p\overline{p}a_0(980) \to p\overline{p}\pi^0\eta$		$(6.8 \pm 1.8) \times 10^{-5}$		–
$p\overline{p}\phi$		$(5.19 \pm 0.33) \times 10^{-5}$		527

$n\overline{n}$		$(2.09 \pm 0.16) \times 10^{-3}$		1231
$n\overline{n}\pi^+\pi^-$		$(4 \pm 4) \times 10^{-3}$		1106
$\Sigma^+\overline{\Sigma}^-$		$(1.50 \pm 0.24) \times 10^{-3}$		992
$\Sigma^0\overline{\Sigma}^0$		$(1.172 \pm 0.032) \times 10^{-3}$	S=1.4	988
$2(\pi^+\pi^-)K^+K^-$		$(3.1 \pm 1.3) \times 10^{-3}$		1320
$p\overline{n}\pi^-$		$(2.12 \pm 0.09) \times 10^{-3}$		1174
$\Xi^-\overline{\Xi}^+$		$(9.7 \pm 0.8) \times 10^{-4}$	S=1.4	807
$\Lambda\overline{\Lambda}$		$(1.89 \pm 0.09) \times 10^{-3}$	S=2.8	1074
$\Lambda\overline{\Sigma}^-\pi^+$ (or c.c.)	[bb]	$(8.3 \pm 0.7) \times 10^{-4}$	S=1.2	950
$pK^-\overline{\Lambda}$+c.c.		$(8.7 \pm 1.1) \times 10^{-4}$		876
$2(K^+K^-)$		$(7.2 \pm 0.8) \times 10^{-4}$		1131
$pK^-\overline{\Sigma}^0$		$(2.9 \pm 0.8) \times 10^{-4}$		819
K^+K^-		$(2.86 \pm 0.21) \times 10^{-4}$		1468
$K^0_S K^0_L$		$(1.95 \pm 0.11) \times 10^{-4}$	S=2.4	1466
$\Lambda\overline{\Lambda}\pi^+\pi^-$		$(4.3 \pm 1.0) \times 10^{-3}$		903
$\Lambda\overline{\Lambda}\eta$		$(1.62 \pm 0.17) \times 10^{-4}$		672
$\Lambda\overline{\Lambda}\pi^0$		$(3.8 \pm 0.4) \times 10^{-5}$		998
$\overline{\Lambda}nK^0_S$ + c.c.		$(6.5 \pm 1.1) \times 10^{-4}$		872
$\pi^+\pi^-$		$(1.47 \pm 0.14) \times 10^{-4}$		1542
$\Lambda\overline{\Sigma}$ + c.c.		$(2.83 \pm 0.23) \times 10^{-5}$		1034
$K^0_S K^0_S$		$< 1.4 \times 10^{-8}$	CL=95%	1466

Radiative decays

3γ		$(1.16 \pm 0.22) \times 10^{-5}$		1548
4γ		$< 9 \times 10^{-6}$	CL=90%	1548
5γ		$< 1.5 \times 10^{-5}$	CL=90%	1548
$\gamma\pi^0\pi^0$		$(1.15 \pm 0.05) \times 10^{-3}$		1543
$\gamma\eta\pi^0$		$(2.14 \pm 0.31) \times 10^{-5}$		1497
$\gamma a_0(980)^0 \to \gamma\eta\pi^0$		$< 2.5 \times 10^{-6}$	CL=95%	–
$\gamma a_2(1320)^0 \to \gamma\eta\pi^0$		$< 6.6 \times 10^{-6}$	CL=95%	–
$\gamma K^0_S K^0_S$		$(8.1 \pm 0.4) \times 10^{-4}$		1466
$\gamma\eta_c(1S)$		(1.7 ± 0.4) %	S=1.5	111
$\gamma\eta_c(1S) \to 3\gamma$		$(3.8 ^{+1.3}_{-1.0}) \times 10^{-6}$	S=1.1	–
$\gamma\pi^+\pi^- 2\pi^0$		$(8.3 \pm 3.1) \times 10^{-3}$		1518
$\gamma\eta\pi\pi$		$(6.1 \pm 1.0) \times 10^{-3}$		1487
$\gamma\eta_2(1870) \to \gamma\eta\pi^+\pi^-$		$(6.2 \pm 2.4) \times 10^{-4}$		–
$\gamma\eta(1405/1475) \to \gamma K\overline{K}\pi$	[nnaa]	$(2.8 \pm 0.6) \times 10^{-3}$	S=1.6	1223
$\gamma\eta(1405/1475) \to \gamma\gamma\rho^0$		$(7.8 \pm 2.0) \times 10^{-5}$	S=1.8	1223
$\gamma\eta(1405/1475) \to \gamma\eta\pi^+\pi^-$		$(3.0 \pm 0.5) \times 10^{-4}$		–
$\gamma\eta(1405/1475) \to \gamma\gamma\phi$		$< 8.2 \times 10^{-5}$	CL=95%	–
$\gamma\eta(1405) \to \gamma\gamma\gamma$		$< 2.63 \times 10^{-6}$	CL=90%	–
$\gamma\eta(1475) \to \gamma\gamma\gamma$		$< 1.86 \times 10^{-6}$	CL=90%	–
$\gamma\rho\rho$		$(4.5 \pm 0.8) \times 10^{-3}$		1340
$\gamma\rho\omega$		$< 5.4 \times 10^{-4}$	CL=90%	1338
$\gamma\rho\phi$		$< 8.8 \times 10^{-5}$	CL=90%	1258
$\gamma\eta'(958)$		$(5.25 \pm 0.07) \times 10^{-3}$	S=1.3	1400
$\gamma 2\pi^+ 2\pi^-$		$(2.8 \pm 0.5) \times 10^{-3}$	S=1.9	1517
$\gamma f_2(1270) f_2(1270)$		$(9.5 \pm 1.7) \times 10^{-4}$		878
$\gamma f_2(1270) f_2(1270)$ (non resonant)		$(8.2 \pm 1.9) \times 10^{-4}$		–
$\gamma K^+K^-\pi^+\pi^-$		$(2.1 \pm 0.6) \times 10^{-3}$		1407
$\gamma f_4(2050)$		$(2.7 \pm 0.7) \times 10^{-3}$		891
$\gamma\omega\omega$		$(1.61 \pm 0.33) \times 10^{-3}$		1336
$\gamma\eta(1405/1475) \to \gamma\rho^0\rho^0$		$(1.7 \pm 0.4) \times 10^{-3}$	S=1.3	1223
$\gamma f_2(1270)$		$(1.64 \pm 0.12) \times 10^{-3}$	S=1.3	1286

$\gamma f_2(1270) \to \gamma K^0_S K^0_S$	$(2.58 \,{}^{+\,0.60}_{-\,0.22}) \times 10^{-5}$		–
$\gamma f_0(1370) \to \gamma K\overline{K}$	$(4.2 \pm 1.5) \times 10^{-4}$		–
$\gamma f_0(1370) \to \gamma K^0_S K^0_S$	$(1.1 \pm 0.4) \times 10^{-5}$		–
$\gamma f_0(1500) \to \gamma K^0_S K^0_S$	$(1.59 \,{}^{+\,0.24}_{-\,0.60}) \times 10^{-5}$		–
$\gamma f_0(1710) \to \gamma K\overline{K}$	$(9.5 \,{}^{+\,1.0}_{-\,0.5}) \times 10^{-4}$	S=1.5	1075
$\gamma f_0(1710) \to \gamma \pi\pi$	$(3.8 \pm 0.5) \times 10^{-4}$		–
$\gamma f_0(1710) \to \gamma \omega\omega$	$(3.1 \pm 1.0) \times 10^{-4}$		–
$\gamma f_0(1710) \to \gamma \eta\eta$	$(2.4 \,{}^{+\,1.2}_{-\,0.7}) \times 10^{-4}$		–
$\gamma \eta$	$(1.108 \pm 0.027) \times 10^{-3}$		1500
$\gamma f_1(1420) \to \gamma K\overline{K}\pi$	$(7.9 \pm 1.3) \times 10^{-4}$		1220
$\gamma f_1(1285)$	$(6.1 \pm 0.8) \times 10^{-4}$		1283
$\gamma f_1(1510) \to \gamma \eta\pi^+\pi^-$	$(4.5 \pm 1.2) \times 10^{-4}$		–
$\gamma f'_2(1525)$	$(5.7 \,{}^{+\,0.8}_{-\,0.5}) \times 10^{-4}$	S=1.5	1177
$\gamma f'_2(1525) \to \gamma K^0_S K^0_S$	$(8.0 \,{}^{+\,0.7}_{-\,0.5}) \times 10^{-5}$		–
$\gamma f'_2(1525) \to \gamma \eta\eta$	$(3.4 \pm 1.4) \times 10^{-5}$		–
$\gamma f_2(1640) \to \gamma \omega\omega$	$(2.8 \pm 1.8) \times 10^{-4}$		–
$\gamma f_2(1910) \to \gamma \omega\omega$	$(2.0 \pm 1.4) \times 10^{-4}$		–
$\gamma f_0(1750) \to \gamma K^0_S K^0_S$	$(1.11 \,{}^{+\,0.20}_{-\,0.33}) \times 10^{-5}$		–
$\gamma f_0(1800) \to \gamma \omega\phi$	$(2.5 \pm 0.6) \times 10^{-4}$		–
$\gamma f_2(1810) \to \gamma \eta\eta$	$(5.4 \,{}^{+\,3.5}_{-\,2.4}) \times 10^{-5}$		–
$\gamma f_2(1950) \to \gamma K^*(892)\overline{K}^*(892)$	$(7.0 \pm 2.2) \times 10^{-4}$		–
$\gamma K^*(892)\overline{K}^*(892)$	$(4.0 \pm 1.3) \times 10^{-3}$		1266
$\gamma \phi\phi$	$(4.0 \pm 1.2) \times 10^{-4}$	S=2.1	1166
$\gamma p\overline{p}$	$(3.8 \pm 1.0) \times 10^{-4}$		1232
$\gamma \eta(2225)$	$(3.14 \,{}^{+\,0.50}_{-\,0.19}) \times 10^{-4}$		752
$\gamma \eta(1760) \to \gamma \rho^0\rho^0$	$(1.3 \pm 0.9) \times 10^{-4}$		1048
$\gamma \eta(1760) \to \gamma \omega\omega$	$(1.98 \pm 0.33) \times 10^{-3}$		–
$\gamma \eta(1760) \to \gamma \gamma\gamma$	$< 4.80 \times 10^{-6}$	CL=90%	–
$\gamma X(1835) \to \gamma \pi^+\pi^-\eta'$	$(2.77 \,{}^{+\,0.34}_{-\,0.40}) \times 10^{-4}$	S=1.1	1006
$\gamma X(1835) \to \gamma p\overline{p}$	$(7.7 \,{}^{+\,1.5}_{-\,0.9}) \times 10^{-5}$		–
$\gamma X(1835) \to \gamma K^0_S K^0_S \eta$	$(3.3 \,{}^{+\,2.0}_{-\,1.3}) \times 10^{-5}$		–
$\gamma X(1835) \to \gamma \gamma\gamma$	$< 3.56 \times 10^{-6}$	CL=90%	–
$\gamma X(1840) \to \gamma 3(\pi^+\pi^-)$	$(2.4 \,{}^{+\,0.7}_{-\,0.8}) \times 10^{-5}$		–
$\gamma (K\overline{K}\pi)\ [J^{PC} = 0^{-+}]$	$(7 \pm 4) \times 10^{-4}$	S=2.1	1442
$\gamma \pi^0$	$(3.56 \pm 0.17) \times 10^{-5}$		1546
$\gamma p\overline{p}\pi^+\pi^-$	$< 7.9 \times 10^{-4}$	CL=90%	1107
$\gamma \Lambda\overline{\Lambda}$	$< 1.3 \times 10^{-4}$	CL=90%	1074
$\gamma f_0(2100) \to \gamma \eta\eta$	$(1.13 \,{}^{+\,0.60}_{-\,0.30}) \times 10^{-4}$		–
$\gamma f_0(2100) \to \gamma \pi\pi$	$(6.2 \pm 1.0) \times 10^{-4}$		–
$\gamma f_0(2200) \to \gamma K\overline{K}$	$(5.9 \pm 1.3) \times 10^{-4}$		–
$\gamma f_0(2200) \to \gamma K^0_S K^0_S$	$(2.72 \,{}^{+\,0.19}_{-\,0.50}) \times 10^{-4}$		–
$\gamma f_J(2220) \to \gamma \pi\pi$	$< 3.9 \times 10^{-5}$	CL=90%	–
$\gamma f_J(2220) \to \gamma K\overline{K}$	$< 4.1 \times 10^{-5}$	CL=90%	–
$\gamma f_J(2220) \to \gamma p\overline{p}$	$(1.5 \pm 0.8) \times 10^{-5}$		–
$\gamma f_0(2330) \to \gamma K^0_S K^0_S$	$(4.9 \pm 0.7) \times 10^{-5}$		–

$\gamma f_2(2340) \to \gamma\eta\eta$		$(5.6 \ ^{+2.4}_{-2.2}) \times 10^{-5}$		–
$\gamma f_2(2340) \to \gamma K^0_S K^0_S$		$(5.5 \ ^{+4.0}_{-1.5}) \times 10^{-5}$		–
$\gamma f_0(1500) \to \gamma\pi\pi$		$(1.09 \pm 0.24) \times 10^{-4}$		1183
$\gamma f_0(1500) \to \gamma\eta\eta$		$(1.7 \ ^{+0.6}_{-1.4}) \times 10^{-5}$		–
$\gamma A \to \gamma$invisible	[ooaa]	$< 6.3 \times 10^{-6}$	CL=90%	–
$\gamma A^0 \to \gamma\mu^+\mu^-$	[ppaa]	$< 5 \times 10^{-6}$	CL=90%	–
Dalitz decays				
$\pi^0 e^+ e^-$		$(7.6 \pm 1.4) \times 10^{-7}$		1546
$\eta e^+ e^-$		$(1.43 \pm 0.07) \times 10^{-5}$		1500
$\eta'(958) e^+ e^-$		$(6.59 \pm 0.18) \times 10^{-5}$		1400
$\eta U \to \eta e^+ e^-$		$< 9.11 \times 10^{-7}$	CL=90%	–
$\eta'(958) U \to \eta'(958) e^+ e^-$		$< 2.0 \times 10^{-7}$	CL=90%	–
$\phi e^+ e^-$		$< 1.2 \times 10^{-7}$	CL=90%	1381
Weak decays				
$D^- e^+ \nu_e$ + c.c.		$< 1.2 \times 10^{-5}$	CL=90%	984
$\overline{D}^0 e^+ e^-$ + c.c.		$< 8.5 \times 10^{-8}$	CL=90%	987
$D^-_s e^+ \nu_e$ + c.c.		$< 1.3 \times 10^{-6}$	CL=90%	923
$D^{*-}_s e^+ \nu_e$ + c.c.		$< 1.8 \times 10^{-6}$	CL=90%	828
$D^- \pi^+$ + c.c.		$< 7.5 \times 10^{-5}$	CL=90%	977
$\overline{D}^0 \overline{K}^0$ + c.c.		$< 1.7 \times 10^{-4}$	CL=90%	898
$\overline{D}^0 \overline{K}^{*0}$ + c.c.		$< 2.5 \times 10^{-6}$	CL=90%	670
$D^-_s \pi^+$ + c.c.		$< 1.3 \times 10^{-4}$	CL=90%	915
$D^-_s \rho^+$ + c.c.		$< 1.3 \times 10^{-5}$	CL=90%	663
Charge conjugation (C), Parity (P), Lepton Family number (LF) violating modes				
$\gamma\gamma$	C	$< 2.7 \times 10^{-7}$	CL=90%	1548
$\gamma\phi$	C	$< 1.4 \times 10^{-6}$	CL=90%	1381
$e^\pm \mu^\mp$	LF	$< 1.6 \times 10^{-7}$	CL=90%	1547
$e^\pm \tau^\mp$	LF	$< 8.3 \times 10^{-6}$	CL=90%	1039
$\mu^\pm \tau^\mp$	LF	$< 2.0 \times 10^{-6}$	CL=90%	1035
$\Lambda^+_c e^-$ +c.c.		$< 6.9 \times 10^{-8}$	CL=90%	–
Other decays				
invisible		$< 7 \times 10^{-4}$	CL=90%	–

See Particle Listings for 3 decay modes that have been seen / not seen.

$\chi_{c0}(1P)$

$I^G(J^{PC}) = 0^+(0^{++})$

Mass $m = 3414.71 \pm 0.30$ MeV
Full width $\Gamma = 10.8 \pm 0.6$ MeV

$\chi_{c0}(1P)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Hadronic decays			
$2(\pi^+\pi^-)$	(2.34 ± 0.18) %		1679
$\rho^0 \pi^+ \pi^-$	$(9.1 \pm 2.9) \times 10^{-3}$		1607
$f_0(980) f_0(980)$	$(6.6 \pm 2.1) \times 10^{-4}$		1391
$\pi^+\pi^-\pi^0\pi^0$	(3.3 ± 0.4) %		1680
$\rho^+\pi^-\pi^0$ + c.c.	(2.9 ± 0.4) %		1607
$4\pi^0$	$(3.3 \pm 0.4) \times 10^{-3}$		1681
$\pi^+\pi^- K^+ K^-$	(1.81 ± 0.14) %		1580

$K_0^*(1430)^0 \overline{K}_0^*(1430)^0 \to \pi^+\pi^- K^+ K^-$	$(9.8\ {}^{+4.0}_{-2.8}) \times 10^{-4}$		–
$K_0^*(1430)^0 \overline{K}_2^*(1430)^0 + \text{c.c.} \to \pi^+\pi^- K^+ K^-$	$(8.0\ {}^{+2.0}_{-2.4}) \times 10^{-4}$		–
$K_1(1270)^+ K^- + \text{c.c.} \to \pi^+\pi^- K^+ K^-$	$(6.3 \pm 1.9) \times 10^{-3}$		–
$K_1(1400)^+ K^- + \text{c.c.} \to \pi^+\pi^- K^+ K^-$	$< 2.7 \times 10^{-3}$	CL=90%	–
$f_0(980) f_0(980)$	$(1.6\ {}^{+1.0}_{-0.9}) \times 10^{-4}$		1391
$f_0(980) f_0(2200)$	$(7.9\ {}^{+2.0}_{-2.5}) \times 10^{-4}$		586
$f_0(1370) f_0(1370)$	$< 2.7 \times 10^{-4}$	CL=90%	1019
$f_0(1370) f_0(1500)$	$< 1.7 \times 10^{-4}$	CL=90%	920
$f_0(1370) f_0(1710)$	$(6.7\ {}^{+3.5}_{-2.3}) \times 10^{-4}$		740
$f_0(1500) f_0(1370)$	$< 1.3 \times 10^{-4}$	CL=90%	920
$f_0(1500) f_0(1500)$	$< 5 \times 10^{-5}$	CL=90%	804
$f_0(1500) f_0(1710)$	$< 7 \times 10^{-5}$	CL=90%	581
$K^+ K^- \pi^+ \pi^- \pi^0$	$(8.6 \pm 0.9) \times 10^{-3}$		1545
$K_S^0 K^\pm \pi^\mp \pi^+ \pi^-$	$(4.2 \pm 0.4) \times 10^{-3}$		1543
$K^+ K^- \pi^0 \pi^0$	$(5.6 \pm 0.9) \times 10^{-3}$		1582
$K^+ \pi^- \overline{K}^0 \pi^0 + \text{c.c.}$	(2.49 ± 0.33) %		1581
$\rho^+ K^- K^0 + \text{c.c.}$	(1.21 ± 0.21) %		1458
$K^*(892)^- K^+ \pi^0 \to K^+ \pi^- \overline{K}^0 \pi^0 + \text{c.c.}$	$(4.6 \pm 1.2) \times 10^{-3}$		–
$K_S^0 K_S^0 \pi^+ \pi^-$	$(5.7 \pm 1.1) \times 10^{-3}$		1579
$K^+ K^- \eta \pi^0$	$(3.0 \pm 0.7) \times 10^{-3}$		1468
$3(\pi^+ \pi^-)$	(1.20 ± 0.18) %		1633
$K^+ \overline{K}^*(892)^0 \pi^- + \text{c.c.}$	$(7.5 \pm 1.6) \times 10^{-3}$		1523
$K^*(892)^0 \overline{K}^*(892)^0$	$(1.7 \pm 0.6) \times 10^{-3}$		1456
$\pi\pi$	$(8.51 \pm 0.33) \times 10^{-3}$		1702
$\pi^0 \eta$	$< 1.8 \times 10^{-4}$		1661
$\pi^0 \eta'$	$< 1.1 \times 10^{-3}$		1570
$\pi^0 \eta_c$	$< 1.6 \times 10^{-3}$	CL=90%	383
$\eta\eta$	$(3.01 \pm 0.19) \times 10^{-3}$		1617
$\eta\eta'$	$(9.1 \pm 1.1) \times 10^{-5}$		1521
$\eta'\eta'$	$(2.17 \pm 0.12) \times 10^{-3}$		1413
$\omega\omega$	$(9.7 \pm 1.1) \times 10^{-4}$		1517
$\omega\phi$	$(1.41 \pm 0.13) \times 10^{-4}$		1447
$\omega K^+ K^-$	$(1.94 \pm 0.21) \times 10^{-3}$		1457
$K^+ K^-$	$(6.05 \pm 0.31) \times 10^{-3}$		1634
$K_S^0 K_S^0$	$(3.16 \pm 0.17) \times 10^{-3}$		1633
$\pi^+ \pi^- \eta$	$< 2.0 \times 10^{-4}$	CL=90%	1651
$\pi^+ \pi^- \eta'$	$< 4 \times 10^{-4}$	CL=90%	1560
$\overline{K}^0 K^+ \pi^- + \text{c.c.}$	$< 9 \times 10^{-5}$	CL=90%	1610
$K^+ K^- \pi^0$	$< 6 \times 10^{-5}$	CL=90%	1611
$K^+ K^- \eta$	$< 2.3 \times 10^{-4}$	CL=90%	1512
$K^+ K^- K_S^0 K_S^0$	$(1.4 \pm 0.5) \times 10^{-3}$		1331
$K_S^0 K_S^0 K_S^0 K_S^0$	$(5.8 \pm 0.5) \times 10^{-4}$		1327
$K^+ K^- K^+ K^-$	$(2.82 \pm 0.29) \times 10^{-3}$		1333
$K^+ K^- \phi$	$(9.7 \pm 2.5) \times 10^{-4}$		1381
$\overline{K}^0 K^+ \pi^- \phi + \text{c.c.}$	$(3.7 \pm 0.6) \times 10^{-3}$		1326
$K^+ K^- \pi^0 \phi$	$(1.90 \pm 0.35) \times 10^{-3}$		1329
$\phi \pi^+ \pi^- \pi^0$	$(1.18 \pm 0.15) \times 10^{-3}$		1525
$\phi\phi$	$(8.0 \pm 0.7) \times 10^{-4}$		1370

$\phi\phi\eta$	$(8.4 \pm 1.0) \times 10^{-4}$		1100
$p\overline{p}$	$(2.21 \pm 0.08) \times 10^{-4}$		1426
$p\overline{p}\pi^0$	$(7.0 \pm 0.7) \times 10^{-4}$	S=1.3	1379
$p\overline{p}\eta$	$(3.5 \pm 0.4) \times 10^{-4}$		1187
$p\overline{p}\omega$	$(5.2 \pm 0.6) \times 10^{-4}$		1043
$p\overline{p}\phi$	$(6.0 \pm 1.4) \times 10^{-5}$		876
$p\overline{p}\pi^+\pi^-$	$(2.1 \pm 0.7) \times 10^{-3}$	S=1.4	1320
$p\overline{p}\pi^0\pi^0$	$(1.04 \pm 0.28) \times 10^{-3}$		1324
$p\overline{p}K^+K^-$ (non-resonant)	$(1.22 \pm 0.26) \times 10^{-4}$		890
$p\overline{p}K^0_SK^0_S$	$< 8.8 \times 10^{-4}$	CL=90%	884
$p\overline{n}\pi^-$	$(1.27 \pm 0.11) \times 10^{-3}$		1376
$\overline{p}n\pi^+$	$(1.37 \pm 0.12) \times 10^{-3}$		1376
$p\overline{n}\pi^-\pi^0$	$(2.34 \pm 0.21) \times 10^{-3}$		1321
$\overline{p}n\pi^+\pi^0$	$(2.21 \pm 0.18) \times 10^{-3}$		1321
$\Lambda\overline{\Lambda}$	$(3.27 \pm 0.24) \times 10^{-4}$		1292
$\Lambda\overline{\Lambda}\pi^+\pi^-$	$(1.18 \pm 0.13) \times 10^{-3}$		1153
$\quad\Lambda\overline{\Lambda}\pi^+\pi^-$ (non-resonant)	$< 5 \times 10^{-4}$	CL=90%	1153
$\quad\Sigma(1385)^+\overline{\Lambda}\pi^-$ + c.c.	$< 5 \times 10^{-4}$	CL=90%	1083
$\quad\Sigma(1385)^-\overline{\Lambda}\pi^+$ + c.c.	$< 5 \times 10^{-4}$	CL=90%	1083
$K^+\overline{p}\Lambda$ + c.c.	$(1.25 \pm 0.12) \times 10^{-3}$	S=1.3	1132
$K^*(892)^+\overline{p}\Lambda$ + c.c.	$(4.8 \pm 0.9) \times 10^{-4}$		845
$K^+\overline{p}\Lambda(1520)$ + c.c.	$(2.9 \pm 0.7) \times 10^{-4}$		859
$\Lambda(1520)\overline{\Lambda}(1520)$	$(3.1 \pm 1.2) \times 10^{-4}$		780
$\Sigma^0\overline{\Sigma}^0$	$(4.68 \pm 0.32) \times 10^{-4}$		1222
$\Sigma^+\overline{p}K^0_S$ + c.c.	$(3.52 \pm 0.27) \times 10^{-4}$		1089
$\Sigma^+\overline{\Sigma}^-$	$(4.6 \pm 0.8) \times 10^{-4}$	S=2.6	1225
$\Sigma(1385)^+\overline{\Sigma}(1385)^-$	$(1.6 \pm 0.6) \times 10^{-4}$		1001
$\Sigma(1385)^-\overline{\Sigma}(1385)^+$	$(2.3 \pm 0.7) \times 10^{-4}$		1001
$K^-\Lambda\overline{\Xi}^+$ + c.c.	$(1.94 \pm 0.35) \times 10^{-4}$		873
$\Xi^0\overline{\Xi}^0$	$(3.1 \pm 0.8) \times 10^{-4}$		1089
$\Xi^-\overline{\Xi}^+$	$(4.8 \pm 0.7) \times 10^{-4}$		1081
$\eta_c\pi^+\pi^-$	$< 7 \times 10^{-4}$	CL=90%	307
Radiative decays			
$\gamma J/\psi(1S)$	(1.40 ± 0.05) %		303
$\gamma\rho^0$	$< 9 \times 10^{-6}$	CL=90%	1619
$\gamma\omega$	$< 8 \times 10^{-6}$	CL=90%	1618
$\gamma\phi$	$< 6 \times 10^{-6}$	CL=90%	1555
$\gamma\gamma$	$(2.04 \pm 0.09) \times 10^{-4}$		1707
$e^+e^-J/\psi(1S)$	$(1.33 \pm 0.29) \times 10^{-4}$		303
$\mu^+\mu^-J/\psi(1S)$	$< 1.9 \times 10^{-5}$	CL=90%	226

$\chi_{c1}(1P)$

$I^G(J^{PC}) = 0^+(1^{++})$

Mass $m = 3510.67 \pm 0.05$ MeV (S = 1.2)
Full width $\Gamma = 0.84 \pm 0.04$ MeV

$\chi_{c1}(1P)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Hadronic decays			
$3(\pi^+\pi^-)$	$(5.8 \pm 1.4) \times 10^{-3}$	S=1.2	1683
$2(\pi^+\pi^-)$	$(7.6 \pm 2.6) \times 10^{-3}$		1728
$\pi^+\pi^-\pi^0\pi^0$	(1.19 ± 0.15) %		1729
$\quad\rho^+\pi^-\pi^0$ + c.c.	(1.45 ± 0.24) %		1658
$\quad\rho^0\pi^+\pi^-$	$(3.9 \pm 3.5) \times 10^{-3}$		1657

$4\pi^0$	$(5.4 \pm 0.8) \times 10^{-4}$		1729
$\pi^+\pi^- K^+ K^-$	$(4.5 \pm 1.0) \times 10^{-3}$		1632
$K^+ K^- \pi^0 \pi^0$	$(1.12 \pm 0.27) \times 10^{-3}$		1634
$K^+ K^- \pi^+ \pi^- \pi^0$	(1.15 ± 0.13) %		1598
$K^0_S K^\pm \pi^\mp \pi^+ \pi^-$	$(7.5 \pm 0.8) \times 10^{-3}$		1596
$K^+ \pi^- \overline{K}{}^0 \pi^0 +$ c.c.	$(8.6 \pm 1.4) \times 10^{-3}$		1632
$\rho^- K^+ \overline{K}{}^0 +$ c.c.	$(5.0 \pm 1.2) \times 10^{-3}$		1514
$K^*(892)^0 \overline{K}{}^0 \pi^0 \to K^+ \pi^- \overline{K}{}^0 \pi^0 +$ c.c.	$(2.3 \pm 0.6) \times 10^{-3}$		–
$K^+ K^- \eta \pi^0$	$(1.12 \pm 0.34) \times 10^{-3}$		1523
$\pi^+ \pi^- K^0_S K^0_S$	$(6.9 \pm 2.9) \times 10^{-4}$		1630
$K^+ K^- \eta$	$(3.2 \pm 1.0) \times 10^{-4}$		1566
$\overline{K}{}^0 K^+ \pi^- +$ c.c.	$(7.0 \pm 0.6) \times 10^{-3}$		1661
$K^*(892)^0 \overline{K}{}^0 +$ c.c.	$(10 \pm 4) \times 10^{-4}$		1602
$K^*(892)^+ K^- +$ c.c.	$(1.4 \pm 0.6) \times 10^{-3}$		1602
$K^*_J(1430)^0 \overline{K}{}^0 +$ c.c. $\to K^0_S K^+ \pi^- +$ c.c.	$< 8 \times 10^{-4}$	CL=90%	–
$K^*_J(1430)^+ K^- +$ c.c. $\to K^0_S K^+ \pi^- +$ c.c.	$< 2.1 \times 10^{-3}$	CL=90%	–
$K^+ K^- \pi^0$	$(1.81 \pm 0.24) \times 10^{-3}$		1662
$\eta \pi^+ \pi^-$	$(4.62 \pm 0.23) \times 10^{-3}$		1701
$a_0(980)^+ \pi^- +$ c.c. $\to \eta \pi^+ \pi^-$	$(3.2 \pm 0.4) \times 10^{-3}$	S=2.2	–
$a_2(1320)^+ \pi^- +$ c.c. $\to \eta \pi^+ \pi^-$	$(1.76 \pm 0.24) \times 10^{-4}$		–
$a_2(1700)^+ \pi^- +$ c.c. $\to \eta \pi^+ \pi^-$	$(4.6 \pm 0.7) \times 10^{-5}$		–
$f_2(1270) \eta \to \eta \pi^+ \pi^-$	$(3.5 \pm 0.6) \times 10^{-4}$		–
$f_4(2050) \eta \to \eta \pi^+ \pi^-$	$(2.5 \pm 0.9) \times 10^{-5}$		–
$\pi_1(1400)^+ \pi^- +$ c.c. $\to \eta \pi^+ \pi^-$	$< 5 \times 10^{-5}$	CL=90%	–
$\pi_1(1600)^+ \pi^- +$ c.c. $\to \eta \pi^+ \pi^-$	$< 1.5 \times 10^{-5}$	CL=90%	–
$\pi_1(2015)^+ \pi^- +$ c.c. $\to \eta \pi^+ \pi^-$	$< 8 \times 10^{-6}$	CL=90%	–
$f_2(1270) \eta$	$(6.7 \pm 1.1) \times 10^{-4}$		1467
$\pi^+ \pi^- \eta'$	$(2.2 \pm 0.4) \times 10^{-3}$		1612
$K^+ K^- \eta'(958)$	$(8.8 \pm 0.9) \times 10^{-4}$		1461
$K^*_0(1430)^+ K^- +$ c.c.	$(6.4 {}^{+2.2}_{-2.8}) \times 10^{-4}$		–
$f_0(980) \eta'(958)$	$(1.6 {}^{+1.4}_{-0.7}) \times 10^{-4}$		1460
$f_0(1710) \eta'(958)$	$(7 {}^{+7}_{-5}) \times 10^{-5}$		1118
$f'_2(1525) \eta'(958)$	$(9 \pm 6) \times 10^{-5}$		1229
$\pi^0 f_0(980) \to \pi^0 \pi^+ \pi^-$	$(3.5 \pm 0.9) \times 10^{-7}$		–
$K^+ \overline{K}{}^*(892)^0 \pi^- +$ c.c.	$(3.2 \pm 2.1) \times 10^{-3}$		1577
$K^*(892)^0 \overline{K}{}^*(892)^0$	$(1.4 \pm 0.4) \times 10^{-3}$		1512
$K^+ K^- K^0_S K^0_S$	$< 4 \times 10^{-4}$	CL=90%	1390
$K^0_S K^0_S K^0_S K^0_S$	$(3.5 \pm 1.0) \times 10^{-5}$		1387
$K^+ K^- K^+ K^-$	$(5.4 \pm 1.1) \times 10^{-4}$		1393
$K^+ K^- \phi$	$(4.1 \pm 1.5) \times 10^{-4}$		1440
$\overline{K}{}^0 K^+ \pi^- \phi +$ c.c.	$(3.3 \pm 0.5) \times 10^{-3}$		1387
$K^+ K^- \pi^0 \phi$	$(1.62 \pm 0.30) \times 10^{-3}$		1390
$\phi \pi^+ \pi^- \pi^0$	$(7.5 \pm 1.0) \times 10^{-4}$		1578
$\omega \omega$	$(5.7 \pm 0.7) \times 10^{-4}$		1571
$\omega K^+ K^-$	$(7.8 \pm 0.9) \times 10^{-4}$		1513
$\omega \phi$	$(2.7 \pm 0.4) \times 10^{-5}$		1503
$\phi \phi$	$(4.2 \pm 0.5) \times 10^{-4}$		1429
$\phi \phi \eta$	$(3.0 \pm 0.5) \times 10^{-4}$		1172
$p \overline{p}$	$(7.60 \pm 0.34) \times 10^{-5}$		1484
$p \overline{p} \pi^0$	$(1.55 \pm 0.18) \times 10^{-4}$		1438

$p\overline{p}\eta$	$(1.45\pm0.25)\times10^{-4}$		1254
$p\overline{p}\omega$	$(2.12\pm0.31)\times10^{-4}$		1117
$p\overline{p}\phi$	$<1.7\times10^{-5}$	CL=90%	962
$p\overline{p}\pi^+\pi^-$	$(5.0\pm1.9)\times10^{-4}$		1381
$p\overline{p}\pi^0\pi^0$	$<5\times10^{-4}$	CL=90%	1385
$p\overline{p}K^+K^-$ (non-resonant)	$(1.27\pm0.22)\times10^{-4}$		974
$p\overline{p}K^0_SK^0_S$	$<4.5\times10^{-4}$	CL=90%	968
$p\overline{n}\pi^-$	$(3.8\pm0.5)\times10^{-4}$		1435
$\overline{p}n\pi^+$	$(3.9\pm0.5)\times10^{-4}$		1435
$p\overline{n}\pi^-\pi^0$	$(1.03\pm0.12)\times10^{-3}$		1383
$\overline{p}n\pi^+\pi^0$	$(1.01\pm0.12)\times10^{-3}$		1383
$\Lambda\overline{\Lambda}$	$(1.14\pm0.11)\times10^{-4}$		1355
$\Lambda\overline{\Lambda}\pi^+\pi^-$	$(2.9\pm0.5)\times10^{-4}$		1223
$\Lambda\overline{\Lambda}\pi^+\pi^-$ (non-resonant)	$(2.5\pm0.6)\times10^{-4}$		1223
$\Sigma(1385)^+\overline{\Lambda}\pi^-$ + c.c.	$<1.3\times10^{-4}$	CL=90%	1157
$\Sigma(1385)^-\overline{\Lambda}\pi^+$ + c.c.	$<1.3\times10^{-4}$	CL=90%	1157
$K^+\overline{p}\Lambda$+c.c.	$(4.2\pm0.4)\times10^{-4}$	S=1.2	1203
$K^*(892)^+\overline{p}\Lambda$+ c.c.	$(4.9\pm0.7)\times10^{-4}$		935
$K^+\overline{p}\Lambda(1520)$ + c.c.	$(1.7\pm0.4)\times10^{-4}$		951
$\Lambda(1520)\overline{\Lambda}(1520)$	$<9\times10^{-5}$	CL=90%	880
$\Sigma^0\overline{\Sigma}^0$	$(4.2\pm0.6)\times10^{-5}$		1288
$\Sigma^+\overline{p}K^0_S$ + c.c.	$(1.53\pm0.12)\times10^{-4}$		1163
$\Sigma^+\overline{\Sigma}^-$	$(3.6\pm0.7)\times10^{-5}$		1291
$\Sigma(1385)^+\overline{\Sigma}(1385)^-$	$<9\times10^{-5}$	CL=90%	1081
$\Sigma(1385)^-\overline{\Sigma}(1385)^+$	$<5\times10^{-5}$	CL=90%	1081
$K^-\Lambda\overline{\Xi}^+$ + c.c.	$(1.35\pm0.24)\times10^{-4}$		963
$\Xi^0\overline{\Xi}^0$	$<6\times10^{-5}$	CL=90%	1163
$\Xi^-\overline{\Xi}^+$	$(8.0\pm2.1)\times10^{-5}$		1155
$\pi^+\pi^-$ + K^+K^-	$<2.1\times10^{-3}$		–
$K^0_SK^0_S$	$<6\times10^{-5}$	CL=90%	1683
$\eta_c\pi^+\pi^-$	$<3.2\times10^{-3}$	CL=90%	413
Radiative decays			
$\gamma J/\psi(1S)$	(34.3 ± 1.0) %		389
$\gamma\rho^0$	$(2.16\pm0.17)\times10^{-4}$		1670
$\gamma\omega$	$(6.8\pm0.8)\times10^{-5}$		1668
$\gamma\phi$	$(2.4\pm0.5)\times10^{-5}$		1607
$\gamma\gamma$	$<6.3\times10^{-6}$	CL=90%	1755
$e^+e^-J/\psi(1S)$	$(3.46\pm0.22)\times10^{-3}$		389
$\mu^+\mu^-J/\psi(1S)$	$(2.33\pm0.29)\times10^{-4}$		335

$h_c(1P)$

$I^G(J^{PC}) = 0^-(1^{+-})$

Mass $m = 3525.38 \pm 0.11$ MeV
Full width $\Gamma = 0.7 \pm 0.4$ MeV

$h_c(1P)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$J/\psi(1S)\pi^+\pi^-$	$<2.3\times10^{-3}$	90%	305
$p\overline{p}$	$<1.5\times10^{-4}$	90%	1492
$p\overline{p}\pi^+\pi^-$	$(2.9\pm0.6)\times10^{-3}$		1390
$\pi^+\pi^-\pi^0$	$(1.6\pm0.5)\times10^{-3}$		1749
$2\pi^+2\pi^-\pi^0$	$(8.1\pm1.8)\times10^{-3}$		1716
$3\pi^+3\pi^-\pi^0$	$<9\times10^{-3}$	90%	1661
$K^+K^-\pi^+\pi^-$	$<6\times10^{-4}$	90%	1640

Radiative decays			
$\gamma\eta$	$(4.7\pm2.1)\times10^{-4}$		1720
$\gamma\eta'(958)$	$(1.5\pm0.4)\times10^{-3}$		1633
$\gamma\eta_c(1S)$	(51 ± 6) %		500

See Particle Listings for 1 decay modes that have been seen / not seen.

$\chi_{c2}(1P)$

$I^G(J^{PC}) = 0^+(2^{++})$

Mass $m = 3556.17 \pm 0.07$ MeV

Full width $\Gamma = 1.97 \pm 0.09$ MeV

$\chi_{c2}(1P)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
Hadronic decays			
$2(\pi^+\pi^-)$	(1.02 ± 0.09) %		1751
$\pi^+\pi^-\pi^0\pi^0$	(1.83 ± 0.23) %		1752
$\rho^+\pi^-\pi^0$ + c.c.	(2.19 ± 0.34) %		1682
$4\pi^0$	$(1.11\pm0.15)\times10^{-3}$		1752
$K^+K^-\pi^0\pi^0$	$(2.1\pm0.4)\times10^{-3}$		1658
$K^+\pi^-\overline{K}^0\pi^0$ + c.c.	(1.38 ± 0.20) %		1657
$\rho^-K^+\overline{K}^0$ + c.c.	$(4.1\pm1.2)\times10^{-3}$		1540
$K^*(892)^0K^-\pi^+\to K^-\pi^+K^0\pi^0$ + c.c.	$(2.9\pm0.8)\times10^{-3}$		–
$K^*(892)^0\overline{K}^0\pi^0\to K^+\pi^-\overline{K}^0\pi^0$ + c.c.	$(3.8\pm0.9)\times10^{-3}$		–
$K^*(892)^-K^+\pi^0\to K^+\pi^-\overline{K}^0\pi^0$ + c.c.	$(3.7\pm0.8)\times10^{-3}$		–
$K^*(892)^+\overline{K}^0\pi^-\to K^+\pi^-\overline{K}^0\pi^0$ + c.c.	$(2.9\pm0.8)\times10^{-3}$		–
$K^+K^-\eta\pi^0$	$(1.3\pm0.4)\times10^{-3}$		1549
$K^+K^-\pi^+\pi^-$	$(8.4\pm0.9)\times10^{-3}$		1656
$K^+K^-\pi^+\pi^-\pi^0$	(1.17 ± 0.13) %		1623
$K^0_SK^\pm\pi^\mp\pi^+\pi^-$	$(7.3\pm0.8)\times10^{-3}$		1621
$K^+\overline{K}^*(892)^0\pi^-$ + c.c.	$(2.1\pm1.1)\times10^{-3}$		1602
$K^*(892)^0\overline{K}^*(892)^0$	$(2.3\pm0.4)\times10^{-3}$		1538
$3(\pi^+\pi^-)$	$(8.6\pm1.8)\times10^{-3}$		1707
$\phi\phi$	$(1.06\pm0.09)\times10^{-3}$		1457
$\phi\phi\eta$	$(5.3\pm0.6)\times10^{-4}$		1206
$\omega\omega$	$(8.4\pm1.0)\times10^{-4}$		1597
ωK^+K^-	$(7.3\pm0.9)\times10^{-4}$		1540
$\omega\phi$	$(9.6\pm2.7)\times10^{-6}$		1529
$\pi\pi$	$(2.23\pm0.09)\times10^{-3}$		1773
$\rho^0\pi^+\pi^-$	$(3.7\pm1.6)\times10^{-3}$		1682
$\pi^+\pi^-\pi^0$ (non-resonant)	$(2.0\pm0.4)\times10^{-5}$		1765
$\rho(770)^\pm\pi^\mp$	$(6\pm4)\times10^{-6}$		–
$\pi^+\pi^-\eta$	$(4.8\pm1.3)\times10^{-4}$		1724
$\pi^+\pi^-\eta'$	$(5.0\pm1.8)\times10^{-4}$		1636
$\eta\eta$	$(5.4\pm0.4)\times10^{-4}$		1692
K^+K^-	$(1.01\pm0.06)\times10^{-3}$		1708
$K^0_SK^0_S$	$(5.2\pm0.4)\times10^{-4}$		1707
$K^*(892)^\pm K^\mp$	$(1.44\pm0.21)\times10^{-4}$		1627
$K^*(892)^0\overline{K}^0$ + c.c.	$(1.24\pm0.27)\times10^{-4}$		1627
$K_2^*(1430)^\pm K^\mp$	$(1.48\pm0.12)\times10^{-3}$		–
$K_2^*(1430)^0\overline{K}^0$ + c.c.	$(1.24\pm0.17)\times10^{-3}$		1443
$K_3^*(1780)^\pm K^\mp$	$(5.2\pm0.8)\times10^{-4}$		–

$K_3^*(1780)^0 \overline{K}^0$ + c.c.	$(5.6 \pm 2.1) \times 10^{-4}$		1276
$a_2(1320)^0 \pi^0$	$(1.29 \pm 0.34) \times 10^{-3}$		–
$a_2(1320)^{\pm} \pi^{\mp}$	$(1.8 \pm 0.6) \times 10^{-3}$		1531
$\overline{K}^0 K^+ \pi^-$ + c.c.	$(1.28 \pm 0.18) \times 10^{-3}$		1685
$K^+ K^- \pi^0$	$(3.0 \pm 0.8) \times 10^{-4}$		1686
$K^+ K^- \eta$	$< 3.2 \times 10^{-4}$	90%	1592
$K^+ K^- \eta'(958)$	$(1.94 \pm 0.34) \times 10^{-4}$		1488
$\eta \eta'$	$(2.2 \pm 0.5) \times 10^{-5}$		1600
$\eta' \eta'$	$(4.6 \pm 0.6) \times 10^{-5}$		1498
$\pi^+ \pi^- K_S^0 K_S^0$	$(2.2 \pm 0.5) \times 10^{-3}$		1655
$K^+ K^- K_S^0 K_S^0$	$< 4 \times 10^{-4}$	90%	1418
$K_S^0 K_S^0 K_S^0 K_S^0$	$(1.13 \pm 0.18) \times 10^{-4}$		1415
$K^+ K^- K^+ K^-$	$(1.65 \pm 0.20) \times 10^{-3}$		1421
$K^+ K^- \phi$	$(1.42 \pm 0.29) \times 10^{-3}$		1468
$\overline{K}^0 K^+ \pi^- \phi$+ c.c.	$(4.8 \pm 0.7) \times 10^{-3}$		1416
$K^+ K^- \pi^0 \phi$	$(2.7 \pm 0.5) \times 10^{-3}$		1419
$\phi \pi^+ \pi^- \pi^0$	$(9.3 \pm 1.2) \times 10^{-4}$		1603
$p \overline{p}$	$(7.33 \pm 0.33) \times 10^{-5}$		1510
$p \overline{p} \pi^0$	$(4.7 \pm 0.4) \times 10^{-4}$		1465
$p \overline{p} \eta$	$(1.74 \pm 0.25) \times 10^{-4}$		1285
$p \overline{p} \omega$	$(3.6 \pm 0.4) \times 10^{-4}$		1152
$p \overline{p} \phi$	$(2.8 \pm 0.9) \times 10^{-5}$		1002
$p \overline{p} \pi^+ \pi^-$	$(1.32 \pm 0.34) \times 10^{-3}$		1410
$p \overline{p} \pi^0 \pi^0$	$(7.8 \pm 2.3) \times 10^{-4}$		1414
$p \overline{p} K^+ K^-$ (non-resonant)	$(1.91 \pm 0.32) \times 10^{-4}$		1013
$p \overline{p} K_S^0 K_S^0$	$< 7.9 \times 10^{-4}$	90%	1007
$p \overline{n} \pi^-$	$(8.5 \pm 0.9) \times 10^{-4}$		1463
$\overline{p} n \pi^+$	$(8.9 \pm 0.8) \times 10^{-4}$		1463
$p \overline{n} \pi^- \pi^0$	$(2.17 \pm 0.18) \times 10^{-3}$		1411
$\overline{p} n \pi^+ \pi^0$	$(2.11 \pm 0.18) \times 10^{-3}$		1411
$\Lambda \overline{\Lambda}$	$(1.84 \pm 0.15) \times 10^{-4}$		1384
$\Lambda \overline{\Lambda} \pi^+ \pi^-$	$(1.25 \pm 0.15) \times 10^{-3}$		1255
$\Lambda \overline{\Lambda} \pi^+ \pi^-$ (non-resonant)	$(6.6 \pm 1.5) \times 10^{-4}$		1255
$\Sigma(1385)^+ \overline{\Lambda} \pi^-$ + c.c.	$< 4 \times 10^{-4}$	90%	1192
$\Sigma(1385)^- \overline{\Lambda} \pi^+$ + c.c.	$< 6 \times 10^{-4}$	90%	1192
$K^+ \overline{p} \Lambda$ + c.c.	$(7.8 \pm 0.5) \times 10^{-4}$		1236
$K^*(892)^+ \overline{p} \Lambda$+ c.c.	$(8.2 \pm 1.1) \times 10^{-4}$		976
$K^+ \overline{p} \Lambda(1520)$+ c.c.	$(2.8 \pm 0.7) \times 10^{-4}$		992
$\Lambda(1520) \overline{\Lambda}(1520)$	$(4.6 \pm 1.5) \times 10^{-4}$		924
$\Sigma^0 \overline{\Sigma}^0$	$(3.7 \pm 0.6) \times 10^{-5}$		1319
$\Sigma^+ \overline{p} K_S^0$+ c.c.	$(8.2 \pm 0.9) \times 10^{-5}$		1197
$\Sigma^+ \overline{\Sigma}^-$	$(3.4 \pm 0.7) \times 10^{-5}$		1322
$\Sigma(1385)^+ \overline{\Sigma}(1385)^-$	$< 1.6 \times 10^{-4}$	90%	1118
$\Sigma(1385)^- \overline{\Sigma}(1385)^+$	$< 8 \times 10^{-5}$	90%	1118
$K^- \Lambda \Xi^+$+ c.c.	$(1.76 \pm 0.32) \times 10^{-4}$		1004
$\Xi^0 \overline{\Xi}^0$	$< 1.0 \times 10^{-4}$	90%	1197
$\Xi^- \overline{\Xi}^+$	$(1.42 \pm 0.32) \times 10^{-4}$		1189
$J/\psi(1S) \pi^+ \pi^- \pi^0$	< 1.5 %	90%	185
$\pi^0 \eta_c$	$< 3.2 \times 10^{-3}$	90%	511
$\eta_c(1S) \pi^+ \pi^-$	$< 5.4 \times 10^{-3}$	90%	459
Radiative decays			
$\gamma J/\psi(1S)$	(19.0 ± 0.5) %		430
$\gamma \rho^0$	$< 1.9 \times 10^{-5}$	90%	1694
$\gamma \omega$	$< 6 \times 10^{-6}$	90%	1692

$\gamma\phi$	$< 7 \times 10^{-6}$	90%	1632
$\gamma\gamma$	$(2.85\pm0.10) \times 10^{-4}$		1778
$e^+e^- J/\psi(1S)$	$(2.15\pm0.14) \times 10^{-3}$		430
$\mu^+\mu^- J/\psi(1S)$	$(2.02\pm0.33) \times 10^{-4}$		381

$\eta_c(2S)$

$I^G(J^{PC}) = 0^+(0^{-+})$

Quantum numbers are quark model predictions.

Mass $m = 3637.5 \pm 1.1$ MeV (S = 1.2)
Full width $\Gamma = 11.3^{+3.2}_{-2.9}$ MeV

$\eta_c(2S)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$K\overline{K}\pi$	(1.9 ± 1.2) %		1729
$K\overline{K}\eta$	$(5 \pm4) \times 10^{-3}$		1637
$K^+K^-\pi^+\pi^-\pi^0$	(1.4 ± 1.0) %		1667
$\gamma\gamma$	$(1.9\pm1.3) \times 10^{-4}$		1819
$\gamma J/\psi(1S)$	< 1.4 %	90%	500
$\pi^+\pi^-\eta_c(1S)$	< 25 %	90%	537

See Particle Listings for 14 decay modes that have been seen / not seen.

$\psi(2S)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 3686.10 \pm 0.06$ MeV (S = 5.9)
Full width $\Gamma = 294 \pm 8$ keV
$\Gamma_{ee} = 2.33 \pm 0.04$ keV

$\psi(2S)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
hadrons	(97.85 ± 0.13) %		–
virtual $\gamma \to$ hadrons	(1.73 ± 0.14) %	S=1.5	–
ggg	(10.6 ± 1.6) %		–
γgg	(1.03 ± 0.29) %		–
light hadrons	(15.4 ± 1.5) %		–
e^+e^-	$(7.93 \pm0.17) \times 10^{-3}$		1843
$\mu^+\mu^-$	$(8.0 \pm0.6) \times 10^{-3}$		1840
$\tau^+\tau^-$	$(3.1 \pm0.4) \times 10^{-3}$		489
Decays into $J/\psi(1S)$ and anything			
$J/\psi(1S)$ anything	(61.4 ± 0.6) %		–
$J/\psi(1S)$ neutrals	(25.38 ± 0.32) %		–
$J/\psi(1S)\pi^+\pi^-$	(34.68 ± 0.30) %		477
$J/\psi(1S)\pi^0\pi^0$	(18.24 ± 0.31) %		481
$J/\psi(1S)\eta$	(3.37 ± 0.05) %		199
$J/\psi(1S)\pi^0$	$(1.268\pm0.032) \times 10^{-3}$		528
Hadronic decays			
$\pi^0 h_c(1P)$	$(8.6 \pm1.3) \times 10^{-4}$		85
$3(\pi^+\pi^-)\pi^0$	$(3.5 \pm1.6) \times 10^{-3}$		1746
$2(\pi^+\pi^-)\pi^0$	$(2.9 \pm1.0) \times 10^{-3}$	S=4.7	1799
$\rho a_2(1320)$	$(2.6 \pm0.9) \times 10^{-4}$		1501
$\pi^+\pi^-\pi^0\pi^0\pi^0$	$(5.3 \pm0.9) \times 10^{-3}$		1800
$\rho^\pm\pi^\mp\pi^0\pi^0$	$< 2.7 \times 10^{-3}$	CL=90%	1737
$p\overline{p}$	$(2.94 \pm0.08) \times 10^{-4}$		1586
$n\overline{n}$	$(3.06 \pm0.15) \times 10^{-4}$		1586

$\Delta^{++}\overline{\Delta}^{--}$	$(1.28 \pm 0.35) \times 10^{-4}$		1371
$\Lambda\overline{\Lambda}\pi^0$	$< 2.9 \times 10^{-6}$	CL=90%	1412
$\Lambda\overline{\Lambda}\eta$	$(2.5 \pm 0.4) \times 10^{-5}$		1197
$\Lambda\overline{p}K^+$	$(1.00 \pm 0.14) \times 10^{-4}$		1327
$K^*(892)^+\overline{p}\Lambda +$ c.c.	$(6.3 \pm 0.7) \times 10^{-5}$		1087
$\Lambda\overline{p}K^+\pi^+\pi^-$	$(1.8 \pm 0.4) \times 10^{-4}$		1167
$\Lambda\overline{\Lambda}\pi^+\pi^-$	$(2.8 \pm 0.6) \times 10^{-4}$		1346
$\Lambda\overline{\Lambda}$	$(3.81 \pm 0.13) \times 10^{-4}$	S=1.4	1467
$\Lambda\overline{\Sigma}^+\pi^- +$ c.c.	$(1.40 \pm 0.13) \times 10^{-4}$		1376
$\Lambda\overline{\Sigma}^-\pi^+ +$ c.c.	$(1.54 \pm 0.14) \times 10^{-4}$		1379
$\Lambda\overline{\Sigma}^0$	$(1.23 \pm 0.24) \times 10^{-5}$		1437
$\Sigma^0\overline{p}K^+ +$ c.c.	$(1.67 \pm 0.18) \times 10^{-5}$		1291
$\Sigma^+\overline{\Sigma}^-$	$(2.32 \pm 0.12) \times 10^{-4}$		1408
$\Sigma^0\overline{\Sigma}^0$	$(2.35 \pm 0.09) \times 10^{-4}$	S=1.1	1405
$\Sigma(1385)^+\overline{\Sigma}(1385)^-$	$(8.5 \pm 0.7) \times 10^{-5}$		1218
$\Sigma(1385)^-\overline{\Sigma}(1385)^+$	$(8.5 \pm 0.8) \times 10^{-5}$		1218
$\Sigma(1385)^0\overline{\Sigma}(1385)^0$	$(6.9 \pm 0.7) \times 10^{-5}$		1218
$\Xi^-\overline{\Xi}^+$	$(2.87 \pm 0.11) \times 10^{-4}$	S=1.1	1284
$\Xi^0\overline{\Xi}^0$	$(2.3 \pm 0.4) \times 10^{-4}$	S=4.2	1291
$\Xi(1530)^0\overline{\Xi}(1530)^0$	$(5.2 {}^{+3.2}_{-1.2}) \times 10^{-5}$		1025
$K^-\Lambda\overline{\Xi}^+ +$ c.c.	$(3.9 \pm 0.4) \times 10^{-5}$		1114
$\Xi(1530)^-\overline{\Xi}(1530)^+$	$(1.15 \pm 0.07) \times 10^{-4}$		1025
$\Xi(1530)^-\overline{\Xi}^+$	$(7.0 \pm 1.2) \times 10^{-6}$		1165
$\Xi(1690)^-\overline{\Xi}^+ \to K^-\Lambda\overline{\Xi}^+ +$ c.c.	$(5.2 \pm 1.6) \times 10^{-6}$		–
$\Xi(1820)^-\overline{\Xi}^+ \to K^-\Lambda\overline{\Xi}^+ +$ c.c.	$(1.20 \pm 0.32) \times 10^{-5}$		–
$K^-\Sigma^0\overline{\Xi}^+ +$ c.c.	$(3.7 \pm 0.4) \times 10^{-5}$		1060
$\Omega^-\overline{\Omega}^+$	$(5.2 \pm 0.4) \times 10^{-5}$		774
$\pi^0 p\overline{p}$	$(1.53 \pm 0.07) \times 10^{-4}$		1543
$N(940)\overline{p} +$ c.c. $\to \pi^0 p\overline{p}$	$(6.4 {}^{+1.8}_{-1.3}) \times 10^{-5}$		–
$N(1440)\overline{p} +$ c.c. $\to \pi^0 p\overline{p}$	$(7.3 {}^{+1.7}_{-1.5}) \times 10^{-5}$	S=2.5	–
$N(1520)\overline{p} +$ c.c. $\to \pi^0 p\overline{p}$	$(6.4 {}^{+2.3}_{-1.8}) \times 10^{-6}$		–
$N(1535)\overline{p} +$ c.c. $\to \pi^0 p\overline{p}$	$(2.5 \pm 1.0) \times 10^{-5}$		–
$N(1650)\overline{p} +$ c.c. $\to \pi^0 p\overline{p}$	$(3.8 {}^{+1.4}_{-1.7}) \times 10^{-5}$		–
$N(1720)\overline{p} +$ c.c. $\to \pi^0 p\overline{p}$	$(1.79 {}^{+0.26}_{-0.70}) \times 10^{-5}$		–
$N(2300)\overline{p} +$ c.c. $\to \pi^0 p\overline{p}$	$(2.6 {}^{+1.2}_{-0.7}) \times 10^{-5}$		–
$N(2570)\overline{p} +$ c.c. $\to \pi^0 p\overline{p}$	$(2.13 {}^{+0.40}_{-0.31}) \times 10^{-5}$		–
$\pi^0 f_0(2100) \to \pi^0 p\overline{p}$	$(1.1 \pm 0.4) \times 10^{-5}$		–
$\eta p\overline{p}$	$(6.0 \pm 0.4) \times 10^{-5}$		1373
$\eta f_0(2100) \to \eta p\overline{p}$	$(1.2 \pm 0.4) \times 10^{-5}$		–
$N(1535)\overline{p} \to \eta p\overline{p}$	$(4.4 \pm 0.7) \times 10^{-5}$		–
$\omega p\overline{p}$	$(6.9 \pm 2.1) \times 10^{-5}$		1247
$\eta' p\overline{p}$	$(1.10 \pm 0.13) \times 10^{-5}$		1141
$\phi p\overline{p}$	$(6.1 \pm 0.6) \times 10^{-6}$		1109
$\phi X(1835) \to \phi p\overline{p}$	$< 1.82 \times 10^{-7}$	CL=90%	–
$\pi^+\pi^- p\overline{p}$	$(6.0 \pm 0.4) \times 10^{-4}$		1491
$p\overline{n}\pi^-$ or c.c.	$(2.48 \pm 0.17) \times 10^{-4}$		–
$p\overline{n}\pi^-\pi^0$	$(3.2 \pm 0.7) \times 10^{-4}$		1492
$2(\pi^+\pi^-\pi^0)$	$(4.8 \pm 1.5) \times 10^{-3}$		1776
$\eta\pi^+\pi^-$	$< 1.6 \times 10^{-4}$	CL=90%	1791

$\eta\pi^+\pi^-\pi^0$	$(9.5 \pm 1.7) \times 10^{-4}$		1778
$2(\pi^+\pi^-)\eta$	$(1.2 \pm 0.6) \times 10^{-3}$		1758
$\pi^+\pi^-\pi^0\pi^0\eta$	$< 4 \times 10^{-4}$	CL=90%	1760
$\eta'\pi^+\pi^-\pi^0$	$(4.5 \pm 2.1) \times 10^{-4}$		1692
$\omega\pi^+\pi^-$	$(7.3 \pm 1.2) \times 10^{-4}$	S=2.1	1748
$b_1^{\pm}\pi^{\mp}$	$(4.0 \pm 0.6) \times 10^{-4}$	S=1.1	1635
$b_1^0\pi^0$	$(2.4 \pm 0.6) \times 10^{-4}$		–
$\omega f_2(1270)$	$(2.2 \pm 0.4) \times 10^{-4}$		1515
$\omega\pi^0\pi^0$	$(1.11 \pm 0.35) \times 10^{-3}$		1749
$\pi^0\pi^0K^+K^-$	$(2.6 \pm 1.3) \times 10^{-4}$		1728
$\pi^+\pi^-K^+K^-$	$(7.3 \pm 0.5) \times 10^{-4}$		1726
$\pi^0\pi^0K_S^0K_L^0$	$(1.3 \pm 0.6) \times 10^{-3}$		1726
$\rho^0K^+K^-$	$(2.2 \pm 0.4) \times 10^{-4}$		1616
$K^*(892)^0\overline{K}_2^*(1430)^0$	$(1.9 \pm 0.5) \times 10^{-4}$		1417
$K^+K^-\pi^+\pi^-\eta$	$(1.3 \pm 0.7) \times 10^{-3}$		1574
$K^+K^-2(\pi^+\pi^-)\pi^0$	$(1.00 \pm 0.31) \times 10^{-3}$		1611
$K^+K^-2(\pi^+\pi^-)$	$(1.9 \pm 0.9) \times 10^{-3}$		1654
$K_1(1270)^{\pm}K^{\mp}$	$(1.00 \pm 0.28) \times 10^{-3}$		1588
$K_S^0K_S^0\pi^+\pi^-$	$(2.2 \pm 0.4) \times 10^{-4}$		1724
$\rho^0p\overline{p}$	$(5.0 \pm 2.2) \times 10^{-5}$		1252
$K^+\overline{K}^*(892)^0\pi^-$ + c.c.	$(6.7 \pm 2.5) \times 10^{-4}$		1674
$2(\pi^+\pi^-)$	$(2.4 \pm 0.6) \times 10^{-4}$	S=2.2	1817
$\rho^0\pi^+\pi^-$	$(2.2 \pm 0.6) \times 10^{-4}$	S=1.4	1750
$K^+K^-\pi^+\pi^-\pi^0$	$(1.26 \pm 0.09) \times 10^{-3}$		1694
$\omega f_0(1710) \to \omega K^+K^-$	$(5.9 \pm 2.2) \times 10^{-5}$		–
$K^*(892)^0K^-\pi^+\pi^0$ + c.c.	$(8.6 \pm 2.2) \times 10^{-4}$		–
$K^*(892)^+K^-\pi^+\pi^-$ + c.c.	$(9.6 \pm 2.8) \times 10^{-4}$		–
$K^*(892)^+K^-\rho^0$ + c.c.	$(7.3 \pm 2.6) \times 10^{-4}$		–
$K^*(892)^0K^-\rho^+$ + c.c.	$(6.1 \pm 1.8) \times 10^{-4}$		–
ηK^+K^-, no $\eta\phi$	$(3.1 \pm 0.4) \times 10^{-5}$		1664
ωK^+K^-	$(1.62 \pm 0.11) \times 10^{-4}$	S=1.1	1614
$\omega K^*(892)^+K^-$ + c.c.	$(2.07 \pm 0.26) \times 10^{-4}$		1482
$\omega K_2^*(1430)^+K^-$ + c.c.	$(6.1 \pm 1.2) \times 10^{-5}$		1252
$\omega\overline{K}^*(892)^0K^0$	$(1.68 \pm 0.30) \times 10^{-4}$		1481
$\omega\overline{K}_2^*(1430)^0K^0$	$(5.8 \pm 2.2) \times 10^{-5}$		1250
$\omega X(1440) \to \omega K_S^0K^-\pi^+$ + c.c.	$(1.6 \pm 0.4) \times 10^{-5}$		–
$\omega X(1440) \to \omega K^+K^-\pi^0$	$(1.09 \pm 0.26) \times 10^{-5}$		–
$\omega f_1(1285) \to \omega K_S^0K^-\pi^+$ + c.c.	$(3.0 \pm 1.0) \times 10^{-6}$		–
$\omega f_1(1285) \to \omega K^+K^-\pi^0$	$(1.2 \pm 0.7) \times 10^{-6}$		–
$3(\pi^+\pi^-)$	$(3.5 \pm 2.0) \times 10^{-4}$	S=2.8	1774
$p\overline{p}\pi^+\pi^-\pi^0$	$(7.3 \pm 0.7) \times 10^{-4}$		1435
K^+K^-	$(7.5 \pm 0.5) \times 10^{-5}$		1776
$K_S^0K_L^0$	$(5.34 \pm 0.33) \times 10^{-5}$		1775
$\pi^+\pi^-\pi^0$	$(2.01 \pm 0.17) \times 10^{-4}$	S=1.7	1830
$\rho(2150)\pi \to \pi^+\pi^-\pi^0$	$(1.9 {}^{+1.2}_{-0.4}) \times 10^{-4}$		–
$\rho(770)\pi \to \pi^+\pi^-\pi^0$	$(3.2 \pm 1.2) \times 10^{-5}$	S=1.8	–
$\pi^+\pi^-$	$(7.8 \pm 2.6) \times 10^{-6}$		1838
$K_1(1400)^{\pm}K^{\mp}$	$< 3.1 \times 10^{-4}$	CL=90%	1532
$K_2^*(1430)^{\pm}K^{\mp}$	$(7.1 {}^{+1.3}_{-0.9}) \times 10^{-5}$		–
$K^+K^-\pi^0$	$(4.07 \pm 0.31) \times 10^{-5}$		1754
$K_S^0K_L^0\pi^0$	$< 3.0 \times 10^{-4}$	CL=90%	1753
$K_S^0K_L^0\eta$	$(1.3 \pm 0.5) \times 10^{-3}$		1661
$K^+K^*(892)^-$ + c.c.	$(2.9 \pm 0.4) \times 10^{-5}$	S=1.2	1698

$K^*(892)^0 \overline{K}^0$ + c.c.	$(1.09 \pm 0.20) \times 10^{-4}$		1697
$\phi \pi^+ \pi^-$	$(1.18 \pm 0.26) \times 10^{-4}$	S=1.5	1690
$\phi f_0(980) \to \pi^+ \pi^-$	$(7.5 \pm 3.3) \times 10^{-5}$	S=1.6	–
$2(K^+ K^-)$	$(6.3 \pm 1.3) \times 10^{-5}$		1499
$\phi K^+ K^-$	$(7.0 \pm 1.6) \times 10^{-5}$		1546
$2(K^+ K^-)\pi^0$	$(1.10 \pm 0.28) \times 10^{-4}$		1440
$\phi \eta$	$(3.10 \pm 0.31) \times 10^{-5}$		1654
$\eta \phi(2170)$, $\phi(2170) \to \phi f_0(980)$, $f_0 \to \pi^+ \pi^-$	$< 2.2 \times 10^{-6}$	CL=90%	–
$\phi \eta'$	$(1.54 \pm 0.20) \times 10^{-5}$		1555
$\phi f_1(1285)$	$(3.0 \pm 1.3) \times 10^{-5}$		1436
$\phi \eta(1405) \to \phi \pi^+ \pi^- \eta$	$(8.5 \pm 1.7) \times 10^{-6}$		–
$\omega \eta'$	$(3.2 ^{+2.5}_{-2.1}) \times 10^{-5}$		1623
$\omega \pi^0$	$(2.1 \pm 0.6) \times 10^{-5}$		1757
$\rho \eta'$	$(1.9 ^{+1.7}_{-1.2}) \times 10^{-5}$		1625
$\rho \eta$	$(2.2 \pm 0.6) \times 10^{-5}$	S=1.1	1717
$\omega \eta$	$< 1.1 \times 10^{-5}$	CL=90%	1715
$\phi \pi^0$	$< 4 \times 10^{-7}$	CL=90%	1699
$\eta_c \pi^+ \pi^- \pi^0$	$< 1.0 \times 10^{-3}$	CL=90%	512
$p \overline{p} K^+ K^-$	$(2.7 \pm 0.7) \times 10^{-5}$		1118
$\overline{\Lambda} n K^0_S$ + c.c.	$(8.1 \pm 1.8) \times 10^{-5}$		1324
$\phi f'_2(1525)$	$(4.4 \pm 1.6) \times 10^{-5}$		1325
$\Theta(1540) \overline{\Theta}(1540) \to K^0_S p K^- \overline{n}$ + c.c.	$< 8.8 \times 10^{-6}$	CL=90%	–
$\Theta(1540) K^- \overline{n} \to K^0_S p K^- \overline{n}$	$< 1.0 \times 10^{-5}$	CL=90%	–
$\Theta(1540) K^0_S \overline{p} \to K^0_S \overline{p} K^+ n$	$< 7.0 \times 10^{-6}$	CL=90%	–
$\overline{\Theta}(1540) K^+ n \to K^0_S \overline{p} K^+ n$	$< 2.6 \times 10^{-5}$	CL=90%	–
$\overline{\Theta}(1540) K^0_S p \to K^0_S p K^- \overline{n}$	$< 6.0 \times 10^{-6}$	CL=90%	–
$K^0_S K^0_S$	$< 4.6 \times 10^{-6}$		1775
$\Lambda_c^+ \overline{p} e^+ e^-$ + c.c.	$< 1.7 \times 10^{-6}$	CL=90%	830

Radiative decays

$\gamma \chi_{c0}(1P)$	(9.79 ± 0.20) %		261
$\gamma \chi_{c1}(1P)$	(9.75 ± 0.24) %		171
$\gamma \chi_{c2}(1P)$	(9.52 ± 0.20) %		128
$\gamma \eta_c(1S)$	$(3.4 \pm 0.5) \times 10^{-3}$	S=1.3	635
$\gamma \eta_c(2S)$	$(7 \pm 5) \times 10^{-4}$		48
$\gamma \pi^0$	$(1.04 \pm 0.22) \times 10^{-6}$	S=1.4	1841
$\gamma \eta'(958)$	$(1.24 \pm 0.04) \times 10^{-4}$		1719
$\gamma f_2(1270)$	$(2.73 ^{+0.29}_{-0.25}) \times 10^{-4}$	S=1.8	1622
$\gamma f_0(1370) \to \gamma K \overline{K}$	$(3.1 \pm 1.7) \times 10^{-5}$		1588
$\gamma f_0(1500)$	$(9.3 \pm 1.9) \times 10^{-5}$		1535
$\gamma f'_2(1525)$	$(3.3 \pm 0.8) \times 10^{-5}$		1531
$\gamma f_0(1710) \to \gamma \pi \pi$	$(3.5 \pm 0.6) \times 10^{-5}$		–
$\gamma f_0(1710) \to \gamma K \overline{K}$	$(6.6 \pm 0.7) \times 10^{-5}$		–
$\gamma f_0(2100) \to \gamma \pi \pi$	$(4.8 \pm 1.0) \times 10^{-6}$		1244
$\gamma f_0(2200) \to \gamma K \overline{K}$	$(3.2 \pm 1.0) \times 10^{-6}$		1193
$\gamma f_J(2220) \to \gamma \pi \pi$	$< 5.8 \times 10^{-6}$	CL=90%	1168
$\gamma f_J(2220) \to \gamma K \overline{K}$	$< 9.5 \times 10^{-6}$	CL=90%	1168
$\gamma \gamma$	$< 1.5 \times 10^{-4}$	CL=90%	1843
$\gamma \eta$	$(9.2 \pm 1.8) \times 10^{-7}$		1802
$\gamma \eta \pi^+ \pi^-$	$(8.7 \pm 2.1) \times 10^{-4}$		1791
$\gamma \eta(1405) \to \gamma K \overline{K} \pi$	$< 9 \times 10^{-5}$	CL=90%	1569

$\gamma\eta(1405) \to \eta\pi^+\pi^-$	$(3.6 \pm 2.5) \times 10^{-5}$		–
$\gamma\eta(1405) \to \gamma f_0(980)\pi^0 \to \gamma\pi^+\pi^-\pi^0$	$< 5.0 \times 10^{-7}$	CL=90%	–
$\gamma\eta(1475) \to K\overline{K}\pi$	$< 1.4 \times 10^{-4}$	CL=90%	–
$\gamma\eta(1475) \to \eta\pi^+\pi^-$	$< 8.8 \times 10^{-5}$	CL=90%	–
$\gamma 2(\pi^+\pi^-)$	$(4.0 \pm 0.6) \times 10^{-4}$		1817
$\gamma K^{*0} K^+\pi^- +$ c.c.	$(3.7 \pm 0.9) \times 10^{-4}$		1674
$\gamma K^{*0}\overline{K}^{*0}$	$(2.4 \pm 0.7) \times 10^{-4}$		1613
$\gamma K^0_S K^+\pi^- +$ c.c.	$(2.6 \pm 0.5) \times 10^{-4}$		1753
$\gamma K^+K^-\pi^+\pi^-$	$(1.9 \pm 0.5) \times 10^{-4}$		1726
$\gamma p\overline{p}$	$(3.9 \pm 0.5) \times 10^{-5}$	S=2.0	1586
$\gamma f_2(1950) \to \gamma p\overline{p}$	$(1.20 \pm 0.22) \times 10^{-5}$		–
$\gamma f_2(2150) \to \gamma p\overline{p}$	$(7.2 \pm 1.8) \times 10^{-6}$		–
$\gamma X(1835) \to \gamma p\overline{p}$	$(4.6 ^{+1.8}_{-4.0}) \times 10^{-6}$		–
$\gamma X \to \gamma p\overline{p}$	[qqaa] $< 2 \times 10^{-6}$	CL=90%	–
$\gamma\pi^+\pi^- p\overline{p}$	$(2.8 \pm 1.4) \times 10^{-5}$		1491
$\gamma 2(\pi^+\pi^-)K^+K^-$	$< 2.2 \times 10^{-4}$	CL=90%	1654
$\gamma 3(\pi^+\pi^-)$	$< 1.7 \times 10^{-4}$	CL=90%	1774
$\gamma K^+K^-K^+K^-$	$< 4 \times 10^{-5}$	CL=90%	1499
$\gamma\gamma J/\psi$	$(3.1 ^{+1.0}_{-1.2}) \times 10^{-4}$		542
$e^+e^-\eta'$	$(1.90 \pm 0.26) \times 10^{-6}$		1719
$e^+e^-\chi_{c0}(1P)$	$(1.06 \pm 0.24) \times 10^{-3}$		261
$e^+e^-\chi_{c1}(1P)$	$(8.5 \pm 0.6) \times 10^{-4}$		171
$e^+e^-\chi_{c2}(1P)$	$(7.0 \pm 0.8) \times 10^{-4}$		128
Weak decays			
$D^0 e^+e^- +$ c.c.	$< 1.4 \times 10^{-7}$	CL=90%	1371
Other decays			
invisible	< 1.6 %	CL=90%	–

$\psi(3770)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 3773.7 \pm 0.4$ MeV (S = 1.4)
Full width $\Gamma = 27.2 \pm 1.0$ MeV
$\Gamma_{ee} = 0.262 \pm 0.018$ keV (S = 1.4)

In addition to the dominant decay mode to $D\overline{D}$, $\psi(3770)$ was found to decay into the final states containing the J/ψ (BAI 05, ADAM 06). ADAMS 06 and HUANG 06A searched for various decay modes with light hadrons and found a statistically significant signal for the decay to $\phi\eta$ only (ADAMS 06).

ψ(3770) DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$D\overline{D}$	$(93 ^{+8}_{-9})$ %	S=2.0	287
$D^0\overline{D}^0$	$(52 ^{+4}_{-5})$ %	S=2.0	287
D^+D^-	(41 ± 4) %	S=2.0	254
$J/\psi\pi^+\pi^-$	$(1.93 \pm 0.28) \times 10^{-3}$		561
$J/\psi\pi^0\pi^0$	$(8.0 \pm 3.0) \times 10^{-4}$		565
$J/\psi\eta$	$(9 \pm 4) \times 10^{-4}$		361
$J/\psi\pi^0$	$< 2.8 \times 10^{-4}$	CL=90%	604
e^+e^-	$(9.6 \pm 0.7) \times 10^{-6}$	S=1.3	1887

Decays to light hadrons

$b_1(1235)\pi$	< 1.4	$\times 10^{-5}$	CL=90%	1684
$\phi\eta'$	< 7	$\times 10^{-4}$	CL=90%	1607
$\omega\eta'$	< 4	$\times 10^{-4}$	CL=90%	1672
$\rho^0\eta'$	< 6	$\times 10^{-4}$	CL=90%	1674
$\phi\eta$	(3.1 ± 0.7)	$\times 10^{-4}$		1703
$\omega\eta$	< 1.4	$\times 10^{-5}$	CL=90%	1762
$\rho^0\eta$	< 5	$\times 10^{-4}$	CL=90%	1764
$\phi\pi^0$	< 3	$\times 10^{-5}$	CL=90%	1746
$\omega\pi^0$	< 6	$\times 10^{-4}$	CL=90%	1803
$\pi^+\pi^-\pi^0$	< 5	$\times 10^{-6}$	CL=90%	1874
$\rho\pi$	< 5	$\times 10^{-6}$	CL=90%	1805
$K^*(892)^+K^-$ + c.c.	< 1.4	$\times 10^{-5}$	CL=90%	1745
$K^*(892)^0\overline{K}^0$ + c.c.	< 1.2	$\times 10^{-3}$	CL=90%	1745
$K^0_S K^0_L$	< 1.2	$\times 10^{-5}$	CL=90%	1820
$2(\pi^+\pi^-)$	< 1.12	$\times 10^{-3}$	CL=90%	1861
$2(\pi^+\pi^-)\pi^0$	< 1.06	$\times 10^{-3}$	CL=90%	1844
$2(\pi^+\pi^-\pi^0)$	< 5.85	%	CL=90%	1821
$\omega\pi^+\pi^-$	< 6.0	$\times 10^{-4}$	CL=90%	1794
$3(\pi^+\pi^-)$	< 9.1	$\times 10^{-3}$	CL=90%	1820
$3(\pi^+\pi^-)\pi^0$	< 1.37	%	CL=90%	1792
$3(\pi^+\pi^-)2\pi^0$	< 11.74	%	CL=90%	1760
$\eta\pi^+\pi^-$	< 1.24	$\times 10^{-3}$	CL=90%	1836
$\pi^+\pi^-2\pi^0$	< 8.9	$\times 10^{-3}$	CL=90%	1862
$\rho^0\pi^+\pi^-$	< 6.9	$\times 10^{-3}$	CL=90%	1796
$\eta 3\pi$	< 1.34	$\times 10^{-3}$	CL=90%	1824
$\eta 2(\pi^+\pi^-)$	< 2.43	%	CL=90%	1804
$\eta\rho^0\pi^+\pi^-$	< 1.45	%	CL=90%	1708
$\eta' 3\pi$	< 2.44	$\times 10^{-3}$	CL=90%	1741
$K^+K^-\pi^+\pi^-$	< 9.0	$\times 10^{-4}$	CL=90%	1773
$\phi\pi^+\pi^-$	< 4.1	$\times 10^{-4}$	CL=90%	1737
$K^+K^-2\pi^0$	< 4.2	$\times 10^{-3}$	CL=90%	1774
$4(\pi^+\pi^-)$	< 1.67	%	CL=90%	1757
$4(\pi^+\pi^-)\pi^0$	< 3.06	%	CL=90%	1720
$\phi f_0(980)$	< 4.5	$\times 10^{-4}$	CL=90%	1597
$K^+K^-\pi^+\pi^-\pi^0$	< 2.36	$\times 10^{-3}$	CL=90%	1741
$K^+K^-\rho^0\pi^0$	< 8	$\times 10^{-4}$	CL=90%	1624
$K^+K^-\rho^+\pi^-$	< 1.46	%	CL=90%	1623
ωK^+K^-	< 3.4	$\times 10^{-4}$	CL=90%	1664
$\phi\pi^+\pi^-\pi^0$	< 3.8	$\times 10^{-3}$	CL=90%	1723
$K^{*0}K^-\pi^+\pi^0$ + c.c.	< 1.62	%	CL=90%	1694
$K^{*+}K^-\pi^+\pi^-$ + c.c.	< 3.23	%	CL=90%	1693
$K^+K^-\pi^+\pi^-2\pi^0$	< 2.67	%	CL=90%	1705
$K^+K^-2(\pi^+\pi^-)$	< 1.03	%	CL=90%	1702
$K^+K^-2(\pi^+\pi^-)\pi^0$	< 3.60	%	CL=90%	1661
ηK^+K^-	< 4.1	$\times 10^{-4}$	CL=90%	1712
$\eta K^+K^-\pi^+\pi^-$	< 1.24	%	CL=90%	1624
$\rho^0K^+K^-$	< 5.0	$\times 10^{-3}$	CL=90%	1666
$2(K^+K^-)$	< 6.0	$\times 10^{-4}$	CL=90%	1552
ϕK^+K^-	< 7.5	$\times 10^{-4}$	CL=90%	1598
$2(K^+K^-)\pi^0$	< 2.9	$\times 10^{-4}$	CL=90%	1494
$2(K^+K^-)\pi^+\pi^-$	< 3.2	$\times 10^{-3}$	CL=90%	1426
$K^0_S K^-\pi^+$	< 3.2	$\times 10^{-3}$	CL=90%	1799
$K^0_S K^-\pi^+\pi^0$	< 1.33	%	CL=90%	1773
$K^0_S K^-\rho^+$	< 6.6	$\times 10^{-3}$	CL=90%	1665

$K^0_S K^- 2\pi^+ \pi^-$	< 8.7	$\times 10^{-3}$	CL=90%	1740
$K^0_S K^- \pi^+ \rho^0$	< 1.6	%	CL=90%	1621
$K^0_S K^- \pi^+ \eta$	< 1.3	%	CL=90%	1670
$K^0_S K^- 2\pi^+ \pi^- \pi^0$	< 4.18	%	CL=90%	1703
$K^0_S K^- 2\pi^+ \pi^- \eta$	< 4.8	%	CL=90%	1570
$K^0_S K^- \pi^+ 2(\pi^+ \pi^-)$	< 1.22	%	CL=90%	1658
$K^0_S K^- \pi^+ 2\pi^0$	< 2.65	%	CL=90%	1742
$K^0_S K^- K^+ K^- \pi^+$	< 4.9	$\times 10^{-3}$	CL=90%	1491
$K^0_S K^- K^+ K^- \pi^+ \pi^0$	< 3.0	%	CL=90%	1427
$K^0_S K^- K^+ K^- \pi^+ \eta$	< 2.2	%	CL=90%	1214
$K^{*0} K^- \pi^+$ + c.c.	< 9.7	$\times 10^{-3}$	CL=90%	1722
$p\overline{p}\pi^0$	< 4	$\times 10^{-5}$	CL=90%	1595
$p\overline{p}\pi^+\pi^-$	< 5.8	$\times 10^{-4}$	CL=90%	1544
$\Lambda\overline{\Lambda}$	< 1.2	$\times 10^{-4}$	CL=90%	1522
$p\overline{p}\pi^+\pi^-\pi^0$	< 1.85	$\times 10^{-3}$	CL=90%	1490
$\omega p\overline{p}$	< 2.9	$\times 10^{-4}$	CL=90%	1310
$\Lambda\overline{\Lambda}\pi^0$	< 7	$\times 10^{-5}$	CL=90%	1469
$p\overline{p}2(\pi^+\pi^-)$	< 2.6	$\times 10^{-3}$	CL=90%	1426
$\eta p\overline{p}$	< 5.4	$\times 10^{-4}$	CL=90%	1431
$\eta p\overline{p}\pi^+\pi^-$	< 3.3	$\times 10^{-3}$	CL=90%	1284
$\rho^0 p\overline{p}$	< 1.7	$\times 10^{-3}$	CL=90%	1314
$p\overline{p}K^+K^-$	< 3.2	$\times 10^{-4}$	CL=90%	1186
$\eta p\overline{p}K^+K^-$	< 6.9	$\times 10^{-3}$	CL=90%	737
$\pi^0 p\overline{p}K^+K^-$	< 1.2	$\times 10^{-3}$	CL=90%	1094
$\phi p\overline{p}$	< 1.3	$\times 10^{-4}$	CL=90%	1178
$\Lambda\overline{\Lambda}\pi^+\pi^-$	< 2.5	$\times 10^{-4}$	CL=90%	1405
$\Lambda\overline{p}K^+$	< 2.8	$\times 10^{-4}$	CL=90%	1387
$\Lambda\overline{p}K^+\pi^+\pi^-$	< 6.3	$\times 10^{-4}$	CL=90%	1234
$\Lambda\overline{\Lambda}\eta$	< 1.9	$\times 10^{-4}$	CL=90%	1263
$\Sigma^+\overline{\Sigma}^-$	< 1.0	$\times 10^{-4}$	CL=90%	1465
$\Sigma^0\overline{\Sigma}^0$	< 4	$\times 10^{-5}$	CL=90%	1462
$\Xi^+\overline{\Xi}^-$	< 1.5	$\times 10^{-4}$	CL=90%	1347
$\Xi^0\overline{\Xi}^0$	< 1.4	$\times 10^{-4}$	CL=90%	1353
Radiative decays				
$\gamma\chi_{c2}$	< 6.4	$\times 10^{-4}$	CL=90%	211
$\gamma\chi_{c1}$	(2.49±0.23)	$\times 10^{-3}$		254
$\gamma\chi_{c0}$	(6.9 ±0.6)	$\times 10^{-3}$		342
$\gamma\eta_c$	< 7	$\times 10^{-4}$	CL=90%	707
$\gamma\eta_c(2S)$	< 9	$\times 10^{-4}$	CL=90%	134
$\gamma\eta'$	< 1.8	$\times 10^{-4}$	CL=90%	1765
$\gamma\eta$	< 1.5	$\times 10^{-4}$	CL=90%	1847
$\gamma\pi^0$	< 2	$\times 10^{-4}$	CL=90%	1884

$\psi_2(3823)$

$I^G(J^{PC}) = 0^-(2^{--})$
I, *J*, *P* need confirmation.

was $\psi(3823)$, $X(3823)$

Mass $m = 3822.2 \pm 1.2$ MeV
Full width $\Gamma < 16$ MeV, CL = 90%

$\psi_3(3842)$

$I^G(J^{PC}) = 0^-(3^{--})$
J, P need confirmation.

Mass $m = 3842.71 \pm 0.20$ MeV
Full width $\Gamma = 2.8 \pm 0.6$ MeV

$\chi_{c1}(3872)$

$I^G(J^{PC}) = 0^+(1^{++})$

also known as $X(3872)$

Mass $m = 3871.69 \pm 0.17$ MeV
$m_{\chi_{c1}(3872)} - m_{J/\psi} = 775 \pm 4$ MeV
Full width $\Gamma < 1.2$ MeV, CL = 90%

χ_{c1}(3872) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\pi^+\pi^- J/\psi(1S)$	> 3.2 %	650
$\omega J/\psi(1S)$	> 2.3 %	†
$D^0 \overline{D}^0 \pi^0$	> 40 %	117
$\overline{D}^{*0} D^0$	> 30 %	4
$\pi^0 \chi_{c1}$	> 2.8 %	319
$\gamma J/\psi$	$> 7 \times 10^{-3}$	697
$\gamma \psi(2S)$	> 4 %	181

See Particle Listings for 3 decay modes that have been seen / not seen.

$Z_c(3900)$

$I^G(J^{PC}) = 1^+(1^{+-})$

was $X(3900)$

Mass $m = 3888.4 \pm 2.5$ MeV (S = 1.7)
Full width $\Gamma = 28.3 \pm 2.5$ MeV

$X(3915)$

$I^G(J^{PC}) = 0^+(0 \text{ or } 2^{++})$

was $\chi_{c0}(3915)$

Mass $m = 3918.4 \pm 1.9$ MeV
Full width $\Gamma = 20 \pm 5$ MeV (S = 1.1)

$\chi_{c2}(3930)$

$I^G(J^{PC}) = 0^+(2^{++})$

Mass $m = 3922.2 \pm 1.0$ MeV (S = 1.6)
Full width $\Gamma = 35.3 \pm 2.8$ MeV (S = 1.4)

$X(4020)^\pm$

$I^G(J^{PC}) = 1^+(?^{?-})$

Mass $m = 4024.1 \pm 1.9$ MeV
Full width $\Gamma = 13 \pm 5$ MeV (S = 1.7)

$\psi(4040)$ [rraa]

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 4039 \pm 1$ MeV
Full width $\Gamma = 80 \pm 10$ MeV
$\Gamma_{ee} = 0.86 \pm 0.07$ keV

Due to the complexity of the $c\overline{c}$ threshold region, in this listing, "seen" ("not seen") means that a cross section for the mode in question has been measured at effective $\sqrt{s}$ near this particle's central mass value, more (less) than 2σ above zero, without regard to any peaking behavior in $\sqrt{s}$ or absence thereof. See mode listing(s) for details and references.

ψ(4040) DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
e^+e^-	$(1.07\pm0.16)\times10^{-5}$		2019
$J/\psi\pi^+\pi^-$	$<4\times10^{-3}$	90%	794
$J/\psi\pi^0\pi^0$	$<2\times10^{-3}$	90%	797
$J/\psi\eta$	$(5.2\pm0.7)\times10^{-3}$		675
$J/\psi\pi^0$	$<2.8\times10^{-4}$	90%	823
$J/\psi\pi^+\pi^-\pi^0$	$<2\times10^{-3}$	90%	746
$\chi_{c1}\gamma$	$<3.4\times10^{-3}$	90%	494
$\chi_{c2}\gamma$	$<5\times10^{-3}$	90%	454
$\chi_{c1}\pi^+\pi^-\pi^0$	<1.1 %	90%	306
$\chi_{c2}\pi^+\pi^-\pi^0$	<3.2 %	90%	233
$h_c(1P)\pi^+\pi^-$	$<3\times10^{-3}$	90%	403
$\phi\pi^+\pi^-$	$<3\times10^{-3}$	90%	1880
$\Lambda\overline{\Lambda}\pi^+\pi^-$	$<2.9\times10^{-4}$	90%	1578
$\Lambda\overline{\Lambda}\pi^0$	$<9\times10^{-5}$	90%	1636
$\Lambda\overline{\Lambda}\eta$	$<3.0\times10^{-4}$	90%	1452
$\Sigma^+\overline{\Sigma}^-$	$<1.3\times10^{-4}$	90%	1632
$\Sigma^0\overline{\Sigma}^0$	$<7\times10^{-5}$	90%	1630
$\Xi^+\overline{\Xi}^-$	$<1.6\times10^{-4}$	90%	1527
$\Xi^0\overline{\Xi}^0$	$<1.8\times10^{-4}$	90%	1533

See Particle Listings for 13 decay modes that have been seen / not seen.

χ_{c1}(4140)

$I^G(J^{PC}) = 0^+(1^{++})$

was $X(4140)$

Mass $m = 4146.8 \pm 2.4$ MeV (S = 1.1)
Full width $\Gamma = 22^{+8}_{-7}$ MeV (S = 1.3)

ψ(4160) [rraa]

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 4191 \pm 5$ MeV
Full width $\Gamma = 70 \pm 10$ MeV
$\Gamma_{ee} = 0.48 \pm 0.22$ keV

Due to the complexity of the $c\overline{c}$ threshold region, in this listing, "seen" ("not seen") means that a cross section for the mode in question has been measured at effective $\sqrt{s}$ near this particle's central mass value, more (less) than 2σ above zero, without regard to any peaking behavior in $\sqrt{s}$ or absence thereof. See mode listing(s) for details and references.

ψ(4160) DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
e^+e^-	$(6.9\pm3.3)\times10^{-6}$		2096
$J/\psi\pi^+\pi^-$	$<3\times10^{-3}$	90%	919
$J/\psi\pi^0\pi^0$	$<3\times10^{-3}$	90%	922
$J/\psi K^+K^-$	$<2\times10^{-3}$	90%	407
$J/\psi\eta$	$<8\times10^{-3}$	90%	822
$J/\psi\pi^0$	$<1\times10^{-3}$	90%	944
$J/\psi\eta'$	$<5\times10^{-3}$	90%	457

$J/\psi\pi^+\pi^-\pi^0$	< 1	$\times 10^{-3}$	90%	879
$\psi(2S)\pi^+\pi^-$	< 4	$\times 10^{-3}$	90%	396
$\chi_{c1}\gamma$	< 5	$\times 10^{-3}$	90%	625
$\chi_{c2}\gamma$	< 1.3	%	90%	587
$\chi_{c1}\pi^+\pi^-\pi^0$	< 2	$\times 10^{-3}$	90%	496
$\chi_{c2}\pi^+\pi^-\pi^0$	< 8	$\times 10^{-3}$	90%	445
$h_c(1P)\pi^+\pi^-$	< 5	$\times 10^{-3}$	90%	556
$h_c(1P)\pi^0\pi^0$	< 2	$\times 10^{-3}$	90%	560
$h_c(1P)\eta$	< 2	$\times 10^{-3}$	90%	348
$h_c(1P)\pi^0$	< 4	$\times 10^{-4}$	90%	600
$\phi\pi^+\pi^-$	< 2	$\times 10^{-3}$	90%	1961
$\gamma\chi_{c1}(3872) \rightarrow \gamma J/\psi\pi^+\pi^-$	< 6.8	$\times 10^{-5}$	90%	–
$\gamma X(3915) \rightarrow \gamma J/\psi\pi^+\pi^-$	< 1.36	$\times 10^{-4}$	90%	–
$\gamma X(3930) \rightarrow \gamma J/\psi\pi^+\pi^-$	< 1.18	$\times 10^{-4}$	90%	–
$\gamma X(3940) \rightarrow \gamma J/\psi\pi^+\pi^-$	< 1.47	$\times 10^{-4}$	90%	–
$\gamma\chi_{c1}(3872) \rightarrow \gamma\gamma J/\psi$	< 1.05	$\times 10^{-4}$	90%	–
$\gamma X(3915) \rightarrow \gamma\gamma J/\psi$	< 1.26	$\times 10^{-4}$	90%	–
$\gamma X(3930) \rightarrow \gamma\gamma J/\psi$	< 8.8	$\times 10^{-5}$	90%	–
$\gamma X(3940) \rightarrow \gamma\gamma J/\psi$	< 1.79	$\times 10^{-4}$	90%	–

See Particle Listings for 15 decay modes that have been seen / not seen.

$\psi(4230)$

$I^G(J^{PC}) = 0^-(1^{--})$

also known as $Y(4230)$; was $X(4230)$

See also $\psi(4260)$ entry in Particle Listings.

Mass $m = 4220 \pm 15$ MeV
Full width $\Gamma = 20$ to 100 MeV

$\chi_{c1}(4274)$

$I^G(J^{PC}) = 0^+(1^{++})$

was $X(4274)$

Mass $m = 4274^{+8}_{-6}$ MeV
Full width $\Gamma = 49 \pm 12$ MeV

$\psi(4360)$

$I^G(J^{PC}) = 0^-(1^{--})$

also known as $Y(4360)$; was $X(4360)$

$\psi(4360)$ MASS $= 4368 \pm 13$ MeV (S = 3.7)
$\psi(4360)$ WIDTH $= 96 \pm 7$ MeV

$\psi(4415)$ [rraa]

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 4421 \pm 4$ MeV
Full width $\Gamma = 62 \pm 20$ MeV
$\Gamma_{ee} = 0.58 \pm 0.07$ keV

Due to the complexity of the $c\overline{c}$ threshold region, in this listing, "seen" ("not seen") means that a cross section for the mode in question has been measured at effective $\sqrt{s}$ near this particle's central mass value, more (less) than 2σ above zero, without regard to any peaking behavior in $\sqrt{s}$ or absence thereof. See mode listing(s) for details and references.

$\psi(4415)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$D^0 D^- \pi^+$ (excl. $D^*(2007)^0 \overline{D}^0$ +c.c., $D^*(2010)^+ D^-$ +c.c.	< 2.3 %	90%	–
$D \overline{D}{}_2^*(2460) \to D^0 D^- \pi^+$ +c.c.	(10 ± 4) %		–
$D^0 D^{*-} \pi^+$ +c.c.	< 11 %	90%	926
$J/\psi \eta$	$< 6 \times 10^{-3}$	90%	1022
$\chi_{c1} \gamma$	$< 8 \times 10^{-4}$	90%	817
$\chi_{c2} \gamma$	$< 4 \times 10^{-3}$	90%	780
$e^+ e^-$	$(9.4 \pm 3.2) \times 10^{-6}$		2210

See Particle Listings for 16 decay modes that have been seen / not seen.

$Z_c(4430)$

$I^G(J^{PC}) = 1^+(1^{+-})$
G, C need confirmation.

was $X(4430)^{\pm}$

Quantum numbers not established.

Mass $m = 4478^{+15}_{-18}$ MeV
Full width $\Gamma = 181 \pm 31$ MeV

$\psi(4660)$

$I^G(J^{PC}) = 0^-(1^{--})$

also known as $Y(4660)$; was $X(4660)$

$\psi(4660)$ MASS $= 4633 \pm 7$ MeV (S = 1.4)
$\psi(4660)$ WIDTH $= 64 \pm 9$ MeV

$b\overline{b}$ MESONS (including possibly non-$q\overline{q}$ states)

$\eta_b(1S)$

$I^G(J^{PC}) = 0^+(0^{-+})$

Mass $m = 9398.7 \pm 2.0$ MeV (S = 1.5)
Full width $\Gamma = 10^{+5}_{-4}$ MeV

$\eta_b(1S)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\mu^+ \mu^-$	$<9 \times 10^{-3}$	90%	4698
$\tau^+ \tau^-$	<8 %	90%	4350

See Particle Listings for 5 decay modes that have been seen / not seen.

$\Upsilon(1S)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 9460.30 \pm 0.26$ MeV (S = 3.3)
Full width $\Gamma = 54.02 \pm 1.25$ keV
$\Gamma_{ee} = 1.340 \pm 0.018$ keV

$\Upsilon(1S)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\tau^+ \tau^-$	(2.60 ± 0.10) %		4384
$e^+ e^-$	(2.38 ± 0.11) %		4730
$\mu^+ \mu^-$	(2.48 ± 0.05) %		4729

Hadronic decays

$g g g$	(81.7 ± 0.7) %			–
$\gamma g g$	(2.2 ± 0.6) %			–
$\eta'(958)$ anything	(2.94 ± 0.24) %			–
$J/\psi(1S)$ anything	$(5.4 \pm 0.4) \times 10^{-4}$		S=1.4	4223
$J/\psi(1S)\eta_c$	$< 2.2 \times 10^{-6}$		CL=90%	3623
$J/\psi(1S)\chi_{c0}$	$< 3.4 \times 10^{-6}$		CL=90%	3429
$J/\psi(1S)\chi_{c1}$	$(3.9 \pm 1.2) \times 10^{-6}$			3382
$J/\psi(1S)\chi_{c2}$	$< 1.4 \times 10^{-6}$		CL=90%	3359
$J/\psi(1S)\eta_c(2S)$	$< 2.2 \times 10^{-6}$		CL=90%	3317
$J/\psi(1S)X(3940)$	$< 5.4 \times 10^{-6}$		CL=90%	3148
$J/\psi(1S)X(4160)$	$< 5.4 \times 10^{-6}$		CL=90%	3018
$X(4350)$ anything, $X \to J/\psi(1S)\phi$	$< 8.1 \times 10^{-6}$		CL=90%	–
$Z_c(3900)^{\pm}$ anything, $Z_c \to J/\psi(1S)\pi^{\pm}$	$< 1.3 \times 10^{-5}$		CL=90%	–
$Z_c(4200)^{\pm}$ anything, $Z_c \to J/\psi(1S)\pi^{\pm}$	$< 6.0 \times 10^{-5}$		CL=90%	–
$Z_c(4430)^{\pm}$ anything, $Z_c \to J/\psi(1S)\pi^{\pm}$	$< 4.9 \times 10^{-5}$		CL=90%	–
$X_{cs}^{\pm}$ anything, $X \to J/\psi K^{\pm}$	$< 5.7 \times 10^{-6}$		CL=90%	–
$\chi_{c1}(3872)$ anything, $\chi_{c1} \to J/\psi(1S)\pi^+\pi^-$	$< 9.5 \times 10^{-6}$		CL=90%	–
$\psi(4260)$ anything, $\psi \to J/\psi(1S)\pi^+\pi^-$	$< 3.8 \times 10^{-5}$		CL=90%	–
$\psi(4260)$ anything, $\psi \to J/\psi(1S)K^+K^-$	$< 7.5 \times 10^{-6}$		CL=90%	–
$\chi_{c1}(4140)$ anything, $\chi_{c1} \to J/\psi(1S)\phi$	$< 5.2 \times 10^{-6}$		CL=90%	–
χ_{c0} anything	$< 4 \times 10^{-3}$		CL=90%	–
χ_{c1} anything	$(1.90 \pm 0.35) \times 10^{-4}$			–
$\chi_{c1}(1P)X_{tetra}$	$< 3.78 \times 10^{-5}$		CL=90%	–
χ_{c2} anything	$(2.8 \pm 0.8) \times 10^{-4}$			–
$\psi(2S)$ anything	$(1.23 \pm 0.20) \times 10^{-4}$			–
$\psi(2S)\eta_c$	$< 3.6 \times 10^{-6}$		CL=90%	3345
$\psi(2S)\chi_{c0}$	$< 6.5 \times 10^{-6}$		CL=90%	3124
$\psi(2S)\chi_{c1}$	$< 4.5 \times 10^{-6}$		CL=90%	3070
$\psi(2S)\chi_{c2}$	$< 2.1 \times 10^{-6}$		CL=90%	3043
$\psi(2S)\eta_c(2S)$	$< 3.2 \times 10^{-6}$		CL=90%	2994
$\psi(2S)X(3940)$	$< 2.9 \times 10^{-6}$		CL=90%	2797
$\psi(2S)X(4160)$	$< 2.9 \times 10^{-6}$		CL=90%	2642
$\psi(4260)$ anything, $\psi \to \psi(2S)\pi^+\pi^-$	$< 7.9 \times 10^{-5}$		CL=90%	–
$\psi(4360)$ anything, $\psi \to \psi(2S)\pi^+\pi^-$	$< 5.2 \times 10^{-5}$		CL=90%	–
$\psi(4660)$ anything, $\psi \to \psi(2S)\pi^+\pi^-$	$< 2.2 \times 10^{-5}$		CL=90%	–
$X(4050)^{\pm}$ anything, $X \to \psi(2S)\pi^{\pm}$	$< 8.8 \times 10^{-5}$		CL=90%	–
$Z_c(4430)^{\pm}$ anything, $Z_c \to \psi(2S)\pi^{\pm}$	$< 6.7 \times 10^{-5}$		CL=90%	–
$Z_c(4200)^+ Z_c(4200)^-$	$< 2.23 \times 10^{-5}$		CL=90%	–
$Z_c(3900)^{\pm} Z_c(4200)^{\mp}$	$< 8.1 \times 10^{-6}$		CL=90%	–
$Z_c(3900)^+ Z_c(3900)^-$	$< 1.8 \times 10^{-6}$		CL=90%	–
$X(4050)^+ X(4050)^-$	$< 1.58 \times 10^{-5}$		CL=90%	–

$X(4250)^+ X(4250)^-$		$< 2.66 \times 10^{-5}$	CL=90%	–
$X(4050)^\pm X(4250)^\mp$		$< 4.42 \times 10^{-5}$	CL=90%	–
$Z_c(4430)^+ Z_c(4430)^-$		$< 2.03 \times 10^{-5}$	CL=90%	–
$X(4055)^\pm X(4055)^\mp$		$< 2.33 \times 10^{-5}$	CL=90%	–
$X(4055)^\pm Z_c(4430)^\mp$		$< 4.55 \times 10^{-5}$	CL=90%	–
$\rho\pi$		$< 3.68 \times 10^{-6}$	CL=90%	4697
$\omega\pi^0$		$< 3.90 \times 10^{-6}$	CL=90%	4697
$\pi^+\pi^-$		$< 5 \times 10^{-4}$	CL=90%	4728
K^+K^-		$< 5 \times 10^{-4}$	CL=90%	4704
$p\overline{p}$		$< 5 \times 10^{-4}$	CL=90%	4636
$\pi^+\pi^-\pi^0$		$(2.1 \pm 0.8) \times 10^{-6}$		4725
ϕK^+K^-		$(2.4 \pm 0.5) \times 10^{-6}$		4622
$\omega\pi^+\pi^-$		$(4.5 \pm 1.0) \times 10^{-6}$		4694
$K^*(892)^0 K^-\pi^+$ + c.c.		$(4.4 \pm 0.8) \times 10^{-6}$		4667
$\phi f'_2(1525)$		$< 1.63 \times 10^{-6}$	CL=90%	4551
$\omega f_2(1270)$		$< 1.79 \times 10^{-6}$	CL=90%	4611
$\rho(770) a_2(1320)$		$< 2.24 \times 10^{-6}$	CL=90%	4605
$K^*(892)^0 \overline{K}^*_2(1430)^0$ + c.c.		$(3.0 \pm 0.8) \times 10^{-6}$		4578
$K_1(1270)^\pm K^\mp$		$< 2.41 \times 10^{-6}$	CL=90%	4634
$K_1(1400)^\pm K^\mp$		$(1.0 \pm 0.4) \times 10^{-6}$		4613
$b_1(1235)^\pm \pi^\mp$		$< 1.25 \times 10^{-6}$	CL=90%	4649
$\pi^+\pi^-\pi^0\pi^0$		$(1.28 \pm 0.30) \times 10^{-5}$		4720
$K^0_S K^+\pi^-$ + c.c.		$(1.6 \pm 0.4) \times 10^{-6}$		4696
$K^*(892)^0 \overline{K}^0$ + c.c.		$(2.9 \pm 0.9) \times 10^{-6}$		4675
$K^*(892)^- K^+$ + c.c.		$< 1.11 \times 10^{-6}$	CL=90%	4675
$f_1(1285)$ anything		$(4.6 \pm 3.1) \times 10^{-3}$		–
$D^*(2010)^\pm$ anything		(2.52 ± 0.20) %		–
$f_1(1285) X_{tetra}$		$< 6.24 \times 10^{-5}$	CL=90%	–
^2H anything		$(2.85 \pm 0.25) \times 10^{-5}$		–
Sum of 100 exclusive modes		(1.200 ± 0.017) %		–

Radiative decays

$\gamma\pi^+\pi^-$		$(6.3 \pm 1.8) \times 10^{-5}$		4728
$\gamma\pi^0\pi^0$		$(1.7 \pm 0.7) \times 10^{-5}$		4728
$\gamma\pi\pi$ (S-wave)		$(4.6 \pm 0.7) \times 10^{-5}$		4728
$\gamma\pi^0\eta$		$< 2.4 \times 10^{-6}$	CL=90%	4713
γK^+K^-	[ssaa]	$(1.14 \pm 0.13) \times 10^{-5}$		4704
$\gamma p\overline{p}$	[ttaa]	$< 6 \times 10^{-6}$	CL=90%	4636
$\gamma 2h^+ 2h^-$		$(7.0 \pm 1.5) \times 10^{-4}$		4720
$\gamma 3h^+ 3h^-$		$(5.4 \pm 2.0) \times 10^{-4}$		4703
$\gamma 4h^+ 4h^-$		$(7.4 \pm 3.5) \times 10^{-4}$		4679
$\gamma\pi^+\pi^- K^+K^-$		$(2.9 \pm 0.9) \times 10^{-4}$		4686
$\gamma 2\pi^+ 2\pi^-$		$(2.5 \pm 0.9) \times 10^{-4}$		4720
$\gamma 3\pi^+ 3\pi^-$		$(2.5 \pm 1.2) \times 10^{-4}$		4703
$\gamma 2\pi^+ 2\pi^- K^+K^-$		$(2.4 \pm 1.2) \times 10^{-4}$		4658
$\gamma\pi^+\pi^- p\overline{p}$		$(1.5 \pm 0.6) \times 10^{-4}$		4604
$\gamma 2\pi^+ 2\pi^- p\overline{p}$		$(4 \pm 6) \times 10^{-5}$		4563
$\gamma 2K^+ 2K^-$		$(2.0 \pm 2.0) \times 10^{-5}$		4601
$\gamma\eta'(958)$		$< 1.9 \times 10^{-6}$	CL=90%	4682
$\gamma\eta$		$< 1.0 \times 10^{-6}$	CL=90%	4714
$\gamma f_0(980)$		$< 3 \times 10^{-5}$	CL=90%	4678
$\gamma f'_2(1525)$		$(2.9 \pm 0.6) \times 10^{-5}$		4608
$\gamma f_2(1270)$		$(1.01 \pm 0.06) \times 10^{-4}$		4644
$\gamma\eta(1405)$		$< 8.2 \times 10^{-5}$	CL=90%	4625
$\gamma f_0(1500)$		$< 1.5 \times 10^{-5}$	CL=90%	4610

$\gamma f_0(1500) \to \gamma K^+ K^-$		$(1.0 \pm 0.4) \times 10^{-5}$		–
$\gamma f_0(1710)$		$< 2.6 \times 10^{-4}$	CL=90%	4577
$\gamma f_0(1710) \to \gamma K^+ K^-$		$(1.01 \pm 0.32) \times 10^{-5}$		–
$\gamma f_0(1710) \to \gamma \pi^+ \pi^-$		$(5.3 \pm 2.0) \times 10^{-6}$		–
$\gamma f_0(1710) \to \gamma \pi^0 \pi^0$		$< 1.4 \times 10^{-6}$	CL=90%	–
$\gamma f_0(1710) \to \gamma \eta \eta$		$< 1.8 \times 10^{-6}$	CL=90%	–
$\gamma f_4(2050)$		$< 5.3 \times 10^{-5}$	CL=90%	4515
$\gamma f_0(2200) \to \gamma K^+ K^-$		$< 2 \times 10^{-4}$	CL=90%	4475
$\gamma f_J(2220) \to \gamma K^+ K^-$		$< 8 \times 10^{-7}$	CL=90%	4469
$\gamma f_J(2220) \to \gamma \pi^+ \pi^-$		$< 6 \times 10^{-7}$	CL=90%	–
$\gamma f_J(2220) \to \gamma p \overline{p}$		$< 1.1 \times 10^{-6}$	CL=90%	–
$\gamma \eta(2225) \to \gamma \phi \phi$		$< 3 \times 10^{-3}$	CL=90%	4469
$\gamma \eta_c(1S)$		$< 5.7 \times 10^{-5}$	CL=90%	4260
$\gamma \chi_{c0}$		$< 6.5 \times 10^{-4}$	CL=90%	4114
$\gamma \chi_{c1}$		$< 2.3 \times 10^{-5}$	CL=90%	4079
$\gamma \chi_{c2}$		$< 7.6 \times 10^{-6}$	CL=90%	4062
$\gamma \chi_{c1}(3872) \to \pi^+ \pi^- J/\psi$		$< 1.6 \times 10^{-6}$	CL=90%	–
$\gamma \chi_{c1}(3872) \to \pi^+ \pi^- \pi^0 J/\psi$		$< 2.8 \times 10^{-6}$	CL=90%	–
$\gamma X(3915) \to \omega J/\psi$		$< 3.0 \times 10^{-6}$	CL=90%	–
$\gamma \chi_{c1}(4140) \to \phi J/\psi$		$< 2.2 \times 10^{-6}$	CL=90%	–
γX	[uuaa]	$< 4.5 \times 10^{-6}$	CL=90%	–
$\gamma X \overline{X}$ ($m_X < 3.1$ GeV)	[vvaa]	$< 1 \times 10^{-3}$	CL=90%	–
$\gamma X \overline{X}$ ($m_X < 4.5$ GeV)	[xxaa]	$< 2.4 \times 10^{-4}$	CL=90%	–
$\gamma X \to \gamma + \geq 4$ prongs	[yyaa]	$< 1.78 \times 10^{-4}$	CL=95%	–
$\gamma a_1^0 \to \gamma \mu^+ \mu^-$	[zzaa]	$< 9 \times 10^{-6}$	CL=90%	–
$\gamma a_1^0 \to \gamma \tau^+ \tau^-$	[ssaa]	$< 1.30 \times 10^{-4}$	CL=90%	–
$\gamma a_1^0 \to \gamma g g$	[aabb]	< 1 %	CL=90%	–
$\gamma a_1^0 \to \gamma s \overline{s}$	[aabb]	$< 1 \times 10^{-3}$	CL=90%	–

Lepton Family number (*LF*) violating modes

$\mu^\pm \tau^\mp$	*LF*	$< 6.0 \times 10^{-6}$	CL=95%	4563

Other decays

invisible		$< 3.0 \times 10^{-4}$	CL=90%	–

$\chi_{b0}(1P)$ [bbbb]

$I^G(J^{PC}) = 0^+(0^{++})$
J needs confirmation.

Mass $m = 9859.44 \pm 0.42 \pm 0.31$ MeV

$\chi_{b0}(1P)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\gamma \Upsilon(1S)$	(1.94 ± 0.27) %		391
$D^0 X$	< 10.4 %	90%	–
$\pi^+ \pi^- K^+ K^- \pi^0$	$< 1.6 \times 10^{-4}$	90%	4875
$2\pi^+ \pi^- K^- K_S^0$	$< 5 \times 10^{-5}$	90%	4875
$2\pi^+ \pi^- K^- K_S^0 2\pi^0$	$< 5 \times 10^{-4}$	90%	4846
$2\pi^+ 2\pi^- 2\pi^0$	$< 2.1 \times 10^{-4}$	90%	4905
$2\pi^+ 2\pi^- K^+ K^-$	$(1.1 \pm 0.6) \times 10^{-4}$		4861
$2\pi^+ 2\pi^- K^+ K^- \pi^0$	$< 2.7 \times 10^{-4}$	90%	4846
$2\pi^+ 2\pi^- K^+ K^- 2\pi^0$	$< 5 \times 10^{-4}$	90%	4828
$3\pi^+ 2\pi^- K^- K_S^0 \pi^0$	$< 1.6 \times 10^{-4}$	90%	4827
$3\pi^+ 3\pi^-$	$< 8 \times 10^{-5}$	90%	4904
$3\pi^+ 3\pi^- 2\pi^0$	$< 6 \times 10^{-4}$	90%	4881

$3\pi^+ 3\pi^- K^+ K^-$	$(2.4 \pm 1.2) \times 10^{-4}$		4827
$3\pi^+ 3\pi^- K^+ K^- \pi^0$	$< 1.0 \times 10^{-3}$	90%	4808
$4\pi^+ 4\pi^-$	$< 8 \times 10^{-5}$	90%	4880
$4\pi^+ 4\pi^- 2\pi^0$	$< 2.1 \times 10^{-3}$	90%	4850
$J/\psi J/\psi$	$< 7 \times 10^{-5}$	90%	3836
$J/\psi \psi(2S)$	$< 1.2 \times 10^{-4}$	90%	3571
$\psi(2S) \psi(2S)$	$< 3.1 \times 10^{-5}$	90%	3273
$J/\psi(1S)$ anything	$< 2.3 \times 10^{-3}$	90%	–

$\chi_{b1}(1P)$ [bbbb]

$I^G(J^{PC}) = 0^+(1^{++})$
J needs confirmation.

Mass $m = 9892.78 \pm 0.26 \pm 0.31$ MeV

$\chi_{b1}(1P)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\gamma \Upsilon(1S)$	(35.2 ± 2.0) %		423
$D^0 X$	(12.6 ± 2.2) %		–
$\pi^+ \pi^- K^+ K^- \pi^0$	$(2.0 \pm 0.6) \times 10^{-4}$		4892
$2\pi^+ \pi^- K^- K^0_S$	$(1.3 \pm 0.5) \times 10^{-4}$		4892
$2\pi^+ \pi^- K^- K^0_S 2\pi^0$	$< 6 \times 10^{-4}$	90%	4863
$2\pi^+ 2\pi^- 2\pi^0$	$(8.0 \pm 2.5) \times 10^{-4}$		4921
$2\pi^+ 2\pi^- K^+ K^-$	$(1.5 \pm 0.5) \times 10^{-4}$		4878
$2\pi^+ 2\pi^- K^+ K^- \pi^0$	$(3.5 \pm 1.2) \times 10^{-4}$		4863
$2\pi^+ 2\pi^- K^+ K^- 2\pi^0$	$(8.6 \pm 3.2) \times 10^{-4}$		4845
$3\pi^+ 2\pi^- K^- K^0_S \pi^0$	$(9.3 \pm 3.3) \times 10^{-4}$		4844
$3\pi^+ 3\pi^-$	$(1.9 \pm 0.6) \times 10^{-4}$		4921
$3\pi^+ 3\pi^- 2\pi^0$	$(1.7 \pm 0.5) \times 10^{-3}$		4898
$3\pi^+ 3\pi^- K^+ K^-$	$(2.6 \pm 0.8) \times 10^{-4}$		4844
$3\pi^+ 3\pi^- K^+ K^- \pi^0$	$(7.5 \pm 2.6) \times 10^{-4}$		4825
$4\pi^+ 4\pi^-$	$(2.6 \pm 0.9) \times 10^{-4}$		4897
$4\pi^+ 4\pi^- 2\pi^0$	$(1.4 \pm 0.6) \times 10^{-3}$		4867
ω anything	(4.9 ± 1.4) %		–
ωX_{tetra}	$< 4.44 \times 10^{-4}$	90%	–
$J/\psi J/\psi$	$< 2.7 \times 10^{-5}$	90%	3857
$J/\psi \psi(2S)$	$< 1.7 \times 10^{-5}$	90%	3594
$\psi(2S) \psi(2S)$	$< 6 \times 10^{-5}$	90%	3298
$J/\psi(1S)$ anything	$< 1.1 \times 10^{-3}$	90%	–
$J/\psi(1S) X_{tetra}$	$< 2.27 \times 10^{-4}$	90%	–

$h_b(1P)$

$I^G(J^{PC}) = 0^-(1^{+-})$

Mass $m = 9899.3 \pm 0.8$ MeV

$h_b(1P)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\eta_b(1S)\gamma$	(52^{+6}_{-5}) %	488

$\chi_{b2}(1P)$ [bbbb]

$I^G(J^{PC}) = 0^+(2^{++})$
J needs confirmation.

Mass $m = 9912.21 \pm 0.26 \pm 0.31$ MeV

$\chi_{b2}(1P)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\gamma\, \Upsilon(1S)$	(18.0 ± 1.0) %		442
$D^0 X$	< 7.9 %	90%	–
$\pi^+\pi^- K^+ K^- \pi^0$	$(8 \pm 5) \times 10^{-5}$		4902
$2\pi^+\pi^- K^- K^0_S$	$< 1.0 \times 10^{-4}$	90%	4901
$2\pi^+\pi^- K^- K^0_S 2\pi^0$	$(5.3\pm2.4) \times 10^{-4}$		4873
$2\pi^+ 2\pi^- 2\pi^0$	$(3.5\pm1.4) \times 10^{-4}$		4931
$2\pi^+ 2\pi^- K^+ K^-$	$(1.1\pm0.4) \times 10^{-4}$		4888
$2\pi^+ 2\pi^- K^+ K^- \pi^0$	$(2.1\pm0.9) \times 10^{-4}$		4872
$2\pi^+ 2\pi^- K^+ K^- 2\pi^0$	$(3.9\pm1.8) \times 10^{-4}$		4855
$3\pi^+ 2\pi^- K^- K^0_S \pi^0$	$< 5 \times 10^{-4}$	90%	4854
$3\pi^+ 3\pi^-$	$(7.0\pm3.1) \times 10^{-5}$		4931
$3\pi^+ 3\pi^- 2\pi^0$	$(1.0\pm0.4) \times 10^{-3}$		4908
$3\pi^+ 3\pi^- K^+ K^-$	$< 8 \times 10^{-5}$	90%	4854
$3\pi^+ 3\pi^- K^+ K^- \pi^0$	$(3.6\pm1.5) \times 10^{-4}$		4835
$4\pi^+ 4\pi^-$	$(8 \pm 4) \times 10^{-5}$		4907
$4\pi^+ 4\pi^- 2\pi^0$	$(1.8\pm0.7) \times 10^{-3}$		4877
$J/\psi J/\psi$	$< 4 \times 10^{-5}$	90%	3869
$J/\psi \psi(2S)$	$< 5 \times 10^{-5}$	90%	3608
$\psi(2S) \psi(2S)$	$< 1.6 \times 10^{-5}$	90%	3313
$J/\psi(1S)$ anything	$(1.5\pm0.4) \times 10^{-3}$		–

$\Upsilon(2S)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 10023.26 \pm 0.31$ MeV
$m_{\Upsilon(3S)} - m_{\Upsilon(2S)} = 331.50 \pm 0.13$ MeV
Full width $\Gamma = 31.98 \pm 2.63$ keV
$\Gamma_{ee} = 0.612 \pm 0.011$ keV

$\Upsilon(2S)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\Upsilon(1S)\pi^+\pi^-$	(17.85 ± 0.26) %		475
$\Upsilon(1S)\pi^0\pi^0$	(8.6 ± 0.4) %		480
$\tau^+\tau^-$	(2.00 ± 0.21) %		4686
$\mu^+\mu^-$	(1.93 ± 0.17) %	S=2.2	5011
e^+e^-	(1.91 ± 0.16) %		5012
$\Upsilon(1S)\pi^0$	$< 4 \times 10^{-5}$	CL=90%	531
$\Upsilon(1S)\eta$	$(2.9 \pm 0.4) \times 10^{-4}$	S=2.0	126
$J/\psi(1S)$ anything	$< 6 \times 10^{-3}$	CL=90%	4533
$J/\psi(1S)\eta_c$	$< 5.4 \times 10^{-6}$	CL=90%	3984
$J/\psi(1S)\chi_{c0}$	$< 3.4 \times 10^{-6}$	CL=90%	3808
$J/\psi(1S)\chi_{c1}$	$< 1.2 \times 10^{-6}$	CL=90%	3765
$J/\psi(1S)\chi_{c2}$	$< 2.0 \times 10^{-6}$	CL=90%	3744
$J/\psi(1S)\eta_c(2S)$	$< 2.5 \times 10^{-6}$	CL=90%	3707
$J/\psi(1S)X(3940)$	$< 2.0 \times 10^{-6}$	CL=90%	3555
$J/\psi(1S)X(4160)$	$< 2.0 \times 10^{-6}$	CL=90%	3440
χ_{c1} anything	$(2.2 \pm 0.5) \times 10^{-4}$		–
$\chi_{c1}(1P)^0 X_{tetra}$	$< 3.67 \times 10^{-5}$	CL=90%	–
χ_{c2} anything	$(2.3 \pm 0.8) \times 10^{-4}$		–

$\psi(2S)\eta_c$	<5.1	$\times 10^{-6}$	CL=90%	3732
$\psi(2S)\chi_{c0}$	<4.7	$\times 10^{-6}$	CL=90%	3536
$\psi(2S)\chi_{c1}$	<2.5	$\times 10^{-6}$	CL=90%	3488
$\psi(2S)\chi_{c2}$	<1.9	$\times 10^{-6}$	CL=90%	3464
$\psi(2S)\eta_c(2S)$	<3.3	$\times 10^{-6}$	CL=90%	3422
$\psi(2S)X(3940)$	<3.9	$\times 10^{-6}$	CL=90%	3250
$\psi(2S)X(4160)$	<3.9	$\times 10^{-6}$	CL=90%	3118
$Z_c(3900)^+ Z_c(3900)^-$	<1.0	$\times 10^{-6}$	CL=90%	–
$Z_c(4200)^+ Z_c(4200)^-$	<1.67	$\times 10^{-5}$	CL=90%	–
$Z_c(3900)^\pm Z_c(4200)^\mp$	<7.3	$\times 10^{-6}$	CL=90%	–
$X(4050)^+ X(4050)^-$	<1.35	$\times 10^{-5}$	CL=90%	–
$X(4250)^+ X(4250)^-$	<2.67	$\times 10^{-5}$	CL=90%	–
$X(4050)^\pm X(4250)^\mp$	<2.72	$\times 10^{-5}$	CL=90%	–
$Z_c(4430)^+ Z_c(4430)^-$	<2.03	$\times 10^{-5}$	CL=90%	–
$X(4055)^\pm X(4055)^\mp$	<1.11	$\times 10^{-5}$	CL=90%	–
$X(4055)^\pm Z_c(4430)^\mp$	<2.11	$\times 10^{-5}$	CL=90%	–
$\overline{^2H}$ anything	$(2.78^{+0.30}_{-0.26})$	$\times 10^{-5}$	S=1.2	–
hadrons	(94 ± 11)	%		–
ggg	(58.8 ± 1.2)	%		–
γgg	(1.87 ± 0.28)	%		–
$\phi K^+ K^-$	(1.6 ± 0.4)	$\times 10^{-6}$		4910
$\omega\pi^+\pi^-$	<2.58	$\times 10^{-6}$	CL=90%	4977
$K^*(892)^0 K^- \pi^+$ + c.c.	(2.3 ± 0.7)	$\times 10^{-6}$		4952
$\phi f'_2(1525)$	<1.33	$\times 10^{-6}$	CL=90%	4842
$\omega f_2(1270)$	<5.7	$\times 10^{-7}$	CL=90%	4899
$\rho(770) a_2(1320)$	<8.8	$\times 10^{-7}$	CL=90%	4894
$K^*(892)^0 \overline{K}^*_2(1430)^0$ + c.c.	(1.5 ± 0.6)	$\times 10^{-6}$		4869
$K_1(1270)^\pm K^\mp$	<3.22	$\times 10^{-6}$	CL=90%	4921
$K_1(1400)^\pm K^\mp$	<8.3	$\times 10^{-7}$	CL=90%	4901
$b_1(1235)^\pm \pi^\mp$	<4.0	$\times 10^{-7}$	CL=90%	4935
$\rho\pi$	<1.16	$\times 10^{-6}$	CL=90%	4981
$\pi^+\pi^-\pi^0$	<8.0	$\times 10^{-7}$	CL=90%	5007
$\omega\pi^0$	<1.63	$\times 10^{-6}$	CL=90%	4980
$\pi^+\pi^-\pi^0\pi^0$	(1.30 ± 0.28)	$\times 10^{-5}$		5002
$K^0_S K^+ \pi^-$ + c.c.	(1.14 ± 0.33)	$\times 10^{-6}$		4979
$K^*(892)^0 \overline{K}^0$ + c.c.	<4.22	$\times 10^{-6}$	CL=90%	4959
$K^*(892)^- K^+$ + c.c.	<1.45	$\times 10^{-6}$	CL=90%	4960
$f_1(1285)$anything	(2.2 ± 1.6)	$\times 10^{-3}$		–
$f_1(1285) X_{tetra}$	<6.47	$\times 10^{-5}$	CL=90%	–
Sum of 100 exclusive modes	(2.90 ± 0.30)	$\times 10^{-3}$		–

Radiative decays

$\gamma\chi_{b1}(1P)$	(6.9 ± 0.4)	%		130
$\gamma\chi_{b2}(1P)$	(7.15 ± 0.35)	%		110
$\gamma\chi_{b0}(1P)$	(3.8 ± 0.4)	%		162
$\gamma f_0(1710)$	<5.9	$\times 10^{-4}$	CL=90%	4867
$\gamma f'_2(1525)$	<5.3	$\times 10^{-4}$	CL=90%	4897
$\gamma f_2(1270)$	<2.41	$\times 10^{-4}$	CL=90%	4930
$\gamma\eta_c(1S)$	<2.7	$\times 10^{-5}$	CL=90%	4567
$\gamma\chi_{c0}$	<1.0	$\times 10^{-4}$	CL=90%	4430
$\gamma\chi_{c1}$	<3.6	$\times 10^{-6}$	CL=90%	4397
$\gamma\chi_{c2}$	<1.5	$\times 10^{-5}$	CL=90%	4381
$\gamma\chi_{c1}(3872) \to \pi^+\pi^- J/\psi$	<8	$\times 10^{-7}$	CL=90%	–
$\gamma\chi_{c1}(3872) \to \pi^+\pi^-\pi^0 J/\psi$	<2.4	$\times 10^{-6}$	CL=90%	–

$\gamma X(3915) \to \omega J/\psi$		< 2.8	$\times 10^{-6}$	CL=90%	–
$\gamma \chi_{c1}(4140) \to \phi J/\psi$		< 1.2	$\times 10^{-6}$	CL=90%	–
$\gamma X(4350) \to \phi J/\psi$		< 1.3	$\times 10^{-6}$	CL=90%	–
$\gamma \eta_b(1S)$		$(5.5 {}^{+1.1}_{-0.9})$	$\times 10^{-4}$	S=1.2	605
$\gamma \eta_b(1S) \to \gamma$Sum of 26 exclusive modes		< 3.7	$\times 10^{-6}$	CL=90%	–
$\gamma X_{b\bar{b}} \to \gamma$Sum of 26 exclusive modes		< 4.9	$\times 10^{-6}$	CL=90%	–
$\gamma X \to \gamma + \geq 4$ prongs	[ccbb]	< 1.95	$\times 10^{-4}$	CL=95%	–
$\gamma A^0 \to \gamma$hadrons		< 8	$\times 10^{-5}$	CL=90%	–
$\gamma a_1^0 \to \gamma \mu^+ \mu^-$		< 8.3	$\times 10^{-6}$	CL=90%	–

Lepton Family number (*LF*) violating modes

$e^{\pm} \tau^{\mp}$	*LF*	< 3.2	$\times 10^{-6}$	CL=90%	4854
$\mu^{\pm} \tau^{\mp}$	*LF*	< 3.3	$\times 10^{-6}$	CL=90%	4854

$\Upsilon_2(1D)$

$I^G(J^{PC}) = 0^-(2^{--})$

was $\Upsilon(1D)$

Mass $m = 10163.7 \pm 1.4$ MeV (S = 1.7)

$\Upsilon_2(1D)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\pi^+ \pi^- \Upsilon(1S)$	$(6.6 \pm 1.6) \times 10^{-3}$	623

See Particle Listings for 3 decay modes that have been seen / not seen.

$\chi_{b0}(2P)$ [bbbb]

$I^G(J^{PC}) = 0^+(0^{++})$
J needs confirmation.

Mass $m = 10232.5 \pm 0.4 \pm 0.5$ MeV

$\chi_{b0}(2P)$ DECAY MODES	Fraction (Γ_i/Γ)		Confidence level	p (MeV/c)
$\gamma \Upsilon(2S)$	(1.38 ± 0.30)	%		207
$\gamma \Upsilon(1S)$	(3.8 ± 1.7)	$\times 10^{-3}$		743
$D^0 X$	< 8.2	%	90%	–
$\pi^+ \pi^- K^+ K^- \pi^0$	< 3.4	$\times 10^{-5}$	90%	5064
$2\pi^+ \pi^- K^- K_S^0$	< 5	$\times 10^{-5}$	90%	5063
$2\pi^+ \pi^- K^- K_S^0 2\pi^0$	< 2.2	$\times 10^{-4}$	90%	5036
$2\pi^+ 2\pi^- 2\pi^0$	< 2.4	$\times 10^{-4}$	90%	5092
$2\pi^+ 2\pi^- K^+ K^-$	< 1.5	$\times 10^{-4}$	90%	5050
$2\pi^+ 2\pi^- K^+ K^- \pi^0$	< 2.2	$\times 10^{-4}$	90%	5035
$2\pi^+ 2\pi^- K^+ K^- 2\pi^0$	< 1.1	$\times 10^{-3}$	90%	5019
$3\pi^+ 2\pi^- K^- K_S^0 \pi^0$	< 7	$\times 10^{-4}$	90%	5018
$3\pi^+ 3\pi^-$	< 7	$\times 10^{-5}$	90%	5091
$3\pi^+ 3\pi^- 2\pi^0$	< 1.2	$\times 10^{-3}$	90%	5070
$3\pi^+ 3\pi^- K^+ K^-$	< 1.5	$\times 10^{-4}$	90%	5017
$3\pi^+ 3\pi^- K^+ K^- \pi^0$	< 7	$\times 10^{-4}$	90%	4999
$4\pi^+ 4\pi^-$	< 1.7	$\times 10^{-4}$	90%	5069
$4\pi^+ 4\pi^- 2\pi^0$	< 6	$\times 10^{-4}$	90%	5039

$\chi_{b1}(2P)$ [bbbb]

$I^G(J^{PC}) = 0^+(1^{++})$
J needs confirmation.

Mass $m = 10255.46 \pm 0.22 \pm 0.50$ MeV
$m_{\chi_{b1}(2P)} - m_{\chi_{b0}(2P)} = 23.5 \pm 1.0$ MeV

$\chi_{b1}(2P)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\omega\Upsilon(1S)$	$(1.63^{+0.40}_{-0.34})$ %	135
$\gamma\Upsilon(2S)$	(18.1 ± 1.9) %	230
$\gamma\Upsilon(1S)$	(9.9 ± 1.0) %	764
$\pi\pi\chi_{b1}(1P)$	$(9.1 \pm 1.3) \times 10^{-3}$	238
$D^0 X$	(8.8 ± 1.7) %	–
$\pi^+\pi^- K^+ K^- \pi^0$	$(3.1 \pm 1.0) \times 10^{-4}$	5075
$2\pi^+\pi^- K^- K^0_S$	$(1.1 \pm 0.5) \times 10^{-4}$	5075
$2\pi^+\pi^- K^- K^0_S 2\pi^0$	$(7.7 \pm 3.2) \times 10^{-4}$	5047
$2\pi^+ 2\pi^- 2\pi^0$	$(5.9 \pm 2.0) \times 10^{-4}$	5104
$2\pi^+ 2\pi^- K^+ K^-$	$(10 \pm 4) \times 10^{-5}$	5062
$2\pi^+ 2\pi^- K^+ K^- \pi^0$	$(5.5 \pm 1.8) \times 10^{-4}$	5047
$2\pi^+ 2\pi^- K^+ K^- 2\pi^0$	$(10 \pm 4) \times 10^{-4}$	5030
$3\pi^+ 2\pi^- K^- K^0_S \pi^0$	$(6.7 \pm 2.6) \times 10^{-4}$	5029
$3\pi^+ 3\pi^-$	$(1.2 \pm 0.4) \times 10^{-4}$	5103
$3\pi^+ 3\pi^- 2\pi^0$	$(1.2 \pm 0.4) \times 10^{-3}$	5081
$3\pi^+ 3\pi^- K^+ K^-$	$(2.0 \pm 0.8) \times 10^{-4}$	5029
$3\pi^+ 3\pi^- K^+ K^- \pi^0$	$(6.1 \pm 2.2) \times 10^{-4}$	5011
$4\pi^+ 4\pi^-$	$(1.7 \pm 0.6) \times 10^{-4}$	5080
$4\pi^+ 4\pi^- 2\pi^0$	$(1.9 \pm 0.7) \times 10^{-3}$	5051

$\chi_{b2}(2P)$ [bbbb]

$I^G(J^{PC}) = 0^+(2^{++})$
J needs confirmation.

Mass $m = 10268.65 \pm 0.22 \pm 0.50$ MeV
$m_{\chi_{b2}(2P)} - m_{\chi_{b1}(2P)} = 13.10 \pm 0.24$ MeV

$\chi_{b2}(2P)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\omega\Upsilon(1S)$	$(1.10^{+0.34}_{-0.30})$ %		194
$\gamma\Upsilon(2S)$	(8.9 ± 1.2) %		242
$\gamma\Upsilon(1S)$	(6.6 ± 0.8) %		777
$\pi\pi\chi_{b2}(1P)$	$(5.1 \pm 0.9) \times 10^{-3}$		229
$D^0 X$	< 2.4 %	90%	–
$\pi^+\pi^- K^+ K^- \pi^0$	$< 1.1 \times 10^{-4}$	90%	5082
$2\pi^+\pi^- K^- K^0_S$	$< 9 \times 10^{-5}$	90%	5082
$2\pi^+\pi^- K^- K^0_S 2\pi^0$	$< 7 \times 10^{-4}$	90%	5054
$2\pi^+ 2\pi^- 2\pi^0$	$(3.9 \pm 1.6) \times 10^{-4}$		5110
$2\pi^+ 2\pi^- K^+ K^-$	$(9 \pm 4) \times 10^{-5}$		5068
$2\pi^+ 2\pi^- K^+ K^- \pi^0$	$(2.4 \pm 1.1) \times 10^{-4}$		5054
$2\pi^+ 2\pi^- K^+ K^- 2\pi^0$	$(4.7 \pm 2.3) \times 10^{-4}$		5037
$3\pi^+ 2\pi^- K^- K^0_S \pi^0$	$< 4 \times 10^{-4}$	90%	5036
$3\pi^+ 3\pi^-$	$(9 \pm 4) \times 10^{-5}$		5110
$3\pi^+ 3\pi^- 2\pi^0$	$(1.2 \pm 0.4) \times 10^{-3}$		5088
$3\pi^+ 3\pi^- K^+ K^-$	$(1.4 \pm 0.7) \times 10^{-4}$		5036
$3\pi^+ 3\pi^- K^+ K^- \pi^0$	$(4.2 \pm 1.7) \times 10^{-4}$		5017

$4\pi^+ 4\pi^-$	$(9 \pm 5) \times 10^{-5}$	5087
$4\pi^+ 4\pi^- 2\pi^0$	$(1.3 \pm 0.5) \times 10^{-3}$	5058

$\Upsilon(3S)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 10355.2 \pm 0.5$ MeV
$m_{\Upsilon(3S)} - m_{\Upsilon(2S)} = 331.50 \pm 0.13$ MeV
Full width $\Gamma = 20.32 \pm 1.85$ keV
$\Gamma_{ee} = 0.443 \pm 0.008$ keV

$\Upsilon(3S)$ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\Upsilon(2S)$anything		(10.6 ± 0.8) %		296
$\Upsilon(2S)\pi^+\pi^-$		(2.82 ± 0.18) %	S=1.6	177
$\Upsilon(2S)\pi^0\pi^0$		(1.85 ± 0.14) %		190
$\Upsilon(2S)\gamma\gamma$		(5.0 ± 0.7) %		327
$\Upsilon(2S)\pi^0$		$< 5.1 \times 10^{-4}$	CL=90%	298
$\Upsilon(1S)\pi^+\pi^-$		(4.37 ± 0.08) %		813
$\Upsilon(1S)\pi^0\pi^0$		(2.20 ± 0.13) %		816
$\Upsilon(1S)\eta$		$< 1 \times 10^{-4}$	CL=90%	677
$\Upsilon(1S)\pi^0$		$< 7 \times 10^{-5}$	CL=90%	846
$h_b(1P)\pi^0$		$< 1.2 \times 10^{-3}$	CL=90%	426
$h_b(1P)\pi^0 \to \gamma\eta_b(1S)\pi^0$		$(4.3 \pm 1.4) \times 10^{-4}$		–
$h_b(1P)\pi^+\pi^-$		$< 1.2 \times 10^{-4}$	CL=90%	353
$\tau^+\tau^-$		(2.29 ± 0.30) %		4863
$\mu^+\mu^-$		(2.18 ± 0.21) %	S=2.1	5177
e^+e^-		(2.18 ± 0.20) %		5178
hadrons		(93 ± 12) %		–
ggg		(35.7 ± 2.6) %		–
γgg		$(9.7 \pm 1.8) \times 10^{-3}$		–
^2H anything		$(2.33 \pm 0.33) \times 10^{-5}$		–
Radiative decays				
$\gamma\chi_{b2}(2P)$		(13.1 ± 1.6) %	S=3.4	86
$\gamma\chi_{b1}(2P)$		(12.6 ± 1.2) %	S=2.4	99
$\gamma\chi_{b0}(2P)$		(5.9 ± 0.6) %	S=1.4	122
$\gamma\chi_{b2}(1P)$		$(10.0 \pm 1.0) \times 10^{-3}$	S=1.7	434
$\gamma\chi_{b1}(1P)$		$(9 \pm 5) \times 10^{-4}$	S=1.8	452
$\gamma\chi_{b0}(1P)$		$(2.7 \pm 0.4) \times 10^{-3}$		484
$\gamma\eta_b(2S)$		$< 6.2 \times 10^{-4}$	CL=90%	350
$\gamma\eta_b(1S)$		$(5.1 \pm 0.7) \times 10^{-4}$		912
$\gamma A^0 \to \gamma$hadrons		$< 8 \times 10^{-5}$	CL=90%	–
$\gamma X \to \gamma + \geq 4$ prongs	[ddbb]	$< 2.2 \times 10^{-4}$	CL=95%	–
$\gamma a_1^0 \to \gamma\mu^+\mu^-$		$< 5.5 \times 10^{-6}$	CL=90%	–
$\gamma a_1^0 \to \gamma\tau^+\tau^-$	[eebb]	$< 1.6 \times 10^{-4}$	CL=90%	–
Lepton Family number (*LF*) violating modes				
$e^\pm\tau^\mp$	*LF*	$< 4.2 \times 10^{-6}$	CL=90%	5025
$\mu^\pm\tau^\mp$	*LF*	$< 3.1 \times 10^{-6}$	CL=90%	5025

$\chi_{b1}(3P)$

$I^G(J^{PC}) = 0^+(1^{++})$

Mass $m = 10513.4 \pm 0.7$ MeV

$\chi_{b2}(3P)$

$I^G(J^{PC}) = 0^+(2^{++})$

Mass $m = 10524.0 \pm 0.8$ MeV

$\Upsilon(4S)$

$I^G(J^{PC}) = 0^-(1^{--})$

also known as $\Upsilon(10580)$

Mass $m = 10579.4 \pm 1.2$ MeV
Full width $\Gamma = 20.5 \pm 2.5$ MeV
$\Gamma_{ee} = 0.272 \pm 0.029$ keV (S = 1.5)

$\Upsilon(4S)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$B\overline{B}$	> 96 %	95%	326
B^+B^-	(51.4 ± 0.6) %		331
D_s^+ anything + c.c.	(17.8 ± 2.6) %		–
$B^0\overline{B}^0$	(48.6 ± 0.6) %		326
$J/\psi K_S^0 + (J/\psi, \eta_c) K_S^0$	$< 4 \times 10^{-7}$	90%	–
non-$B\overline{B}$	< 4 %	95%	–
e^+e^-	$(1.57 \pm 0.08) \times 10^{-5}$		5290
$\rho^+\rho^-$	$< 5.7 \times 10^{-6}$	90%	5233
$K^*(892)^0\overline{K}^0$	$< 2.0 \times 10^{-6}$	90%	5240
$J/\psi(1S)$ anything	$< 1.9 \times 10^{-4}$	95%	–
D^{*+} anything + c.c.	< 7.4 %	90%	5099
ϕ anything	(7.1 ± 0.6) %		5240
$\phi\eta$	$< 1.8 \times 10^{-6}$	90%	5226
$\phi\eta'$	$< 4.3 \times 10^{-6}$	90%	5196
$\rho\eta$	$< 1.3 \times 10^{-6}$	90%	5247
$\rho\eta'$	$< 2.5 \times 10^{-6}$	90%	5217
$\Upsilon(1S)$ anything	$< 4 \times 10^{-3}$	90%	1053
$\Upsilon(1S)\pi^+\pi^-$	$(8.2 \pm 0.4) \times 10^{-5}$		1026
$\Upsilon(1S)\eta$	$(1.81 \pm 0.18) \times 10^{-4}$		924
$\Upsilon(1S)\eta'$	$(3.4 \pm 0.9) \times 10^{-5}$		–
$\Upsilon(2S)\pi^+\pi^-$	$(8.2 \pm 0.8) \times 10^{-5}$		468
$h_b(1P)\eta$	$(2.18 \pm 0.21) \times 10^{-3}$		390
^2H anything	$< 1.3 \times 10^{-5}$	90%	–
Double Radiative Decays			
$\gamma\gamma\Upsilon(D) \to \gamma\gamma\eta\Upsilon(1S)$	$< 2.3 \times 10^{-5}$	90%	–

See Particle Listings for 1 decay modes that have been seen / not seen.

$Z_b(10610)$

$I^G(J^{PC}) = 1^+(1^{+-})$

was $X(10610)$

Mass $m = 10607.2 \pm 2.0$ MeV
Full width $\Gamma = 18.4 \pm 2.4$ MeV

$Z_b(10610)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Upsilon(1S)\pi^+$	$(5.4^{+1.9}_{-1.5}) \times 10^{-3}$	1077
$\Upsilon(2S)\pi^+$	$(3.6^{+1.1}_{-0.8})$ %	551
$\Upsilon(3S)\pi^+$	$(2.1^{+0.8}_{-0.6})$ %	207

$h_b(1P)\pi^+$	$(3.5^{+1.2}_{-0.9})$ %	671
$h_b(2P)\pi^+$	$(4.7^{+1.7}_{-1.3})$ %	313
$B^+\overline{B}^{*0} + B^{*+}\overline{B}^0$	$(85.6^{+2.1}_{-2.9})$ %	–

See Particle Listings for 4 decay modes that have been seen / not seen.

$Z_b(10650)$

$I^G(J^{PC}) = 1^+(1^{+-})$
I, G, C need confirmation.

was $X(10650)^{\pm}$

Mass $m = 10652.2 \pm 1.5$ MeV
Full width $\Gamma = 11.5 \pm 2.2$ MeV

$Z_b(10650)^-$ decay modes are charge conjugates of the modes below.

$Z_b(10650)^+$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Upsilon(1S)\pi^+$	$(1.7^{+0.8}_{-0.6}) \times 10^{-3}$	1117
$\Upsilon(2S)\pi^+$	$(1.4^{+0.6}_{-0.4})$ %	595
$\Upsilon(3S)\pi^+$	$(1.6^{+0.7}_{-0.5})$ %	259
$h_b(1P)\pi^+$	$(8.4^{+2.9}_{-2.4})$ %	714
$h_b(2P)\pi^+$	(15 ± 4) %	360
$B^{*+}\overline{B}^{*0}$	(74^{+4}_{-6}) %	122

See Particle Listings for 2 decay modes that have been seen / not seen.

$\Upsilon(10860)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 10885.2^{+2.6}_{-1.6}$ MeV
Full width $\Gamma = 37 \pm 4$ MeV
$\Gamma_{ee} = 0.31 \pm 0.07$ keV (S = 1.3)

$\Upsilon(10860)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$B\overline{B}X$	$(76.2^{+2.7}_{-4.0})$ %		–
$B\overline{B}$	(5.5 ± 1.0) %		1322
$B\overline{B}^* +$ c.c.	(13.7 ± 1.6) %		–
$B^*\overline{B}^*$	(38.1 ± 3.4) %		1127
$B\overline{B}^{(*)}\pi$	< 19.7 %	90%	1015
$B\overline{B}\pi$	(0.0 ± 1.2) %		1015
$B^*\overline{B}\pi + B\overline{B}^*\pi$	(7.3 ± 2.3) %		–
$B^*\overline{B}^*\pi$	(1.0 ± 1.4) %		739
$B\overline{B}\pi\pi$	< 8.9 %	90%	551
$B_s^{(*)}\overline{B}_s^{(*)}$	(20.1 ± 3.1) %		905
$B_s\overline{B}_s$	$(5 \pm 5) \times 10^{-3}$		905
$B_s\overline{B}_s^* +$ c.c.	(1.35 ± 0.32) %		–
$B_s^*\overline{B}_s^*$	(17.6 ± 2.7) %		543
no open-bottom	$(3.8^{+5.0}_{-0.5})$ %		–
e^+e^-	$(8.3 \pm 2.1) \times 10^{-6}$		5443
$K^*(892)^0\overline{K}^0$	$< 1.0 \times 10^{-5}$	90%	5395
$\Upsilon(1S)\pi^+\pi^-$	$(5.3 \pm 0.6) \times 10^{-3}$		1306

$\Upsilon(2S)\pi^+\pi^-$	$(7.8 \pm 1.3) \times 10^{-3}$		783
$\Upsilon(3S)\pi^+\pi^-$	$(4.8 {+1.9 \atop -1.7}) \times 10^{-3}$		440
$\Upsilon(1S)K^+K^-$	$(6.1 \pm 1.8) \times 10^{-4}$		959
$\eta\Upsilon_J(1D)$	$(4.8 \pm 1.1) \times 10^{-3}$		–
$h_b(1P)\pi^+\pi^-$	$(3.5 {+1.0 \atop -1.3}) \times 10^{-3}$		903
$h_b(2P)\pi^+\pi^-$	$(5.7 {+1.7 \atop -2.1}) \times 10^{-3}$		544
$\chi_{bJ}(1P)\pi^+\pi^-\pi^0$	$(2.5 \pm 2.3) \times 10^{-3}$		894
$\chi_{b0}(1P)\pi^+\pi^-\pi^0$	$< 6.3 \times 10^{-3}$	90%	894
$\chi_{b0}(1P)\omega$	$< 3.9 \times 10^{-3}$	90%	631
$\chi_{b0}(1P)(\pi^+\pi^-\pi^0)_{\text{non}-\omega}$	$< 4.8 \times 10^{-3}$	90%	–
$\chi_{b1}(1P)\pi^+\pi^-\pi^0$	$(1.85 \pm 0.33) \times 10^{-3}$		861
$\chi_{b1}(1P)\omega$	$(1.57 \pm 0.30) \times 10^{-3}$		582
$\chi_{b1}(1P)(\pi^+\pi^-\pi^0)_{\text{non}-\omega}$	$(5.2 \pm 1.9) \times 10^{-4}$		–
$\chi_{b2}(1P)\pi^+\pi^-\pi^0$	$(1.17 \pm 0.30) \times 10^{-3}$		841
$\chi_{b2}(1P)\omega$	$(6.0 \pm 2.7) \times 10^{-4}$		552
$\chi_{b2}(1P)(\pi^+\pi^-\pi^0)_{\text{non}-\omega}$	$(6 \pm 4) \times 10^{-4}$		–
$\gamma X_b \to \gamma\Upsilon(1S)\omega$	$< 3.8 \times 10^{-5}$	90%	–

Inclusive Decays.

These decay modes are submodes of one or more of the decay modes above.

ϕ anything	$(13.8 {+2.4 \atop -1.7})$ %		–
D^0 anything + c.c.	(108 ± 8) %		–
D_s anything + c.c.	(46 ± 6) %		–
J/ψ anything	(2.06 ± 0.21) %		–
B^0 anything + c.c.	(77 ± 8) %		–
B^+ anything + c.c.	(72 ± 6) %		–

$\Upsilon(11020)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 11000 \pm 4$ MeV
Full width $\Gamma = 24^{+8}_{-6}$ MeV
$\Gamma_{ee} = 0.130 \pm 0.030$ keV

Υ(11020) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
e^+e^-	$(5.4^{+1.9}_{-2.1}) \times 10^{-6}$	5500
$\chi_{bJ}(1P)\pi^+\pi^-\pi^0$	$(9 {+9 \atop -8}) \times 10^{-3}$	1007

See Particle Listings for 2 decay modes that have been seen / not seen.

NOTES

In this Summary Table:

When a quantity has "(S = ...)" to its right, the error on the quantity has been enlarged by the "scale factor" S, defined as $S = \sqrt{\chi^2/(N-1)}$, where N is the number of measurements used in calculating the quantity.

A decay momentum p is given for each decay mode. For a 2-body decay, p is the momentum of each decay product in the rest frame of the decaying particle. For a 3-or-more-body decay, p is the largest momentum any of the products can have in this frame.

[*a*] See the review on "Form Factors for Radiative Pion and Kaon Decays" for definitions and details.

[*b*] Measurements of $\Gamma(e^+\nu_e)/\Gamma(\mu^+\nu_\mu)$ always include decays with γ's, and measurements of $\Gamma(e^+\nu_e\gamma)$ and $\Gamma(\mu^+\nu_\mu\gamma)$ never include low-energy γ's. Therefore, since no clean separation is possible, we consider the modes with γ's to be subreactions of the modes without them, and let $[\Gamma(e^+\nu_e) + \Gamma(\mu^+\nu_\mu)]/\Gamma_{\text{total}} = 100\%$.

[*c*] See the $\pi^\pm$ Particle Listings in the Full *Review of Particle Physics* for the energy limits used in this measurement; low-energy γ's are not included.

[*d*] Derived from an analysis of neutrino-oscillation experiments.

[*e*] Astrophysical and cosmological arguments give limits of order 10^{-13}.

[*f*] Forbidden by angular momentum conservation.

[*g*] *C* parity forbids this to occur as a single-photon process.

[*h*] The $\omega\rho$ interference is then due to $\omega\rho$ mixing only, and is expected to be small. If $e\mu$ universality holds, $\Gamma(\rho^0 \to \mu^+\mu^-) = \Gamma(\rho^0 \to e^+e^-) \times 0.99785$.

[*i*] See the "Note on $a_1(1260)$" in the $a_1(1260)$ Particle Listings in PDG 06, Journal of Physics **G33** 1 (2006).

[*j*] Our estimate. See the Particle Listings for details.

[*k*] See the note on "Non-$q\overline{q}$ mesons" in the Particle Listings in PDG 06, Journal of Physics **G33** 1 (2006).

[*l*] See also the $\omega(1650)$.

[*n*] See also the $\omega(1420)$.

[*o*] See the note in the $K^\pm$ Particle Listings in the Full *Review of Particle Physics.*

[*p*] Neglecting photon channels. See, *e.g.*, A. Pais and S.B. Treiman, Phys. Rev. **D12**, 2744 (1975).

[*q*] The definition of the slope parameters of the $K \to 3\pi$ Dalitz plot is as follows (see also "Note on Dalitz Plot Parameters for $K \to 3\pi$ Decays" in the $K^\pm$ Particle Listings in the Full *Review of Particle Physics*):

$$|M|^2 = 1 + g(s_3 - s_0)/m^2_{\pi^+} + \cdots .$$

[*r*] For more details and definitions of parameters see Particle Listings in the Full *Review of Particle Physics.*

[*s*] See the $K^\pm$ Particle Listings in the Full *Review of Particle Physics* for the energy limits used in this measurement.

[*t*] Most of this radiative mode, the low-momentum γ part, is also included in the parent mode listed without γ's.

[*u*] Structure-dependent part.

[*v*] Direct-emission branching fraction.

[*x*] Violates angular-momentum conservation.

[*y*] Derived from measured values of ϕ_{+-}, ϕ_{00}, $|\eta|$, $|m_{K^0_L} - m_{K^0_S}|$, and $\tau_{K^0_S}$, as described in the introduction to "Tests of Conservation Laws."

[*z*] The *CP*-violation parameters are defined as follows (see also "Note on *CP* Violation in $K_S \to 3\pi$" and "Note on *CP* Violation in K^0_L Decay" in the Particle Listings in the Full *Review of Particle Physics*):

$$\eta_{+-} = |\eta_{+-}|e^{i\phi_{+-}} = \frac{A(K^0_L \to \pi^+\pi^-)}{A(K^0_S \to \pi^+\pi^-)} = \epsilon + \epsilon'$$

$$\eta_{00} = |\eta_{00}|e^{i\phi_{00}} = \frac{A(K^0_L \to \pi^0\pi^0)}{A(K^0_S \to \pi^0\pi^0)} = \epsilon - 2\epsilon'$$

$$\delta = \frac{\Gamma(K^0_L \to \pi^-\ell^+\nu) - \Gamma(K^0_L \to \pi^+\ell^-\nu)}{\Gamma(K^0_L \to \pi^-\ell^+\nu) + \Gamma(K^0_L \to \pi^+\ell^-\nu)} ,$$

$$\mathrm{Im}(\eta_{+-0})^2 = \frac{\Gamma(K^0_S \to \pi^+\pi^-\pi^0)^{CP\ \mathrm{viol.}}}{\Gamma(K^0_L \to \pi^+\pi^-\pi^0)} ,$$

$$\mathrm{Im}(\eta_{000})^2 = \frac{\Gamma(K^0_S \to \pi^0\pi^0\pi^0)}{\Gamma(K^0_L \to \pi^0\pi^0\pi^0)} .$$

where for the last two relations *CPT* is assumed valid, *i.e.*, $\mathrm{Re}(\eta_{+-0}) \simeq 0$ and $\mathrm{Re}(\eta_{000}) \simeq 0$.

[*aa*] See the K^0_S Particle Listings in the Full *Review of Particle Physics* for the energy limits used in this measurement.

[*bb*] The value is for the sum of the charge states or particle/antiparticle states indicated.

[*cc*] $\mathrm{Re}(\epsilon'/\epsilon) = \epsilon'/\epsilon$ to a very good approximation provided the phases satisfy *CPT* invariance.

[*dd*] This mode includes gammas from inner bremsstrahlung but not the direct emission mode $K^0_L \to \pi^+\pi^-\gamma(\mathrm{DE})$.

[*ee*] See the K^0_L Particle Listings in the Full *Review of Particle Physics* for the energy limits used in this measurement.

[*ff*] Allowed by higher-order electroweak interactions.

[*gg*] Violates *CP* in leading order. Test of direct *CP* violation since the indirect *CP*-violating and *CP*-conserving contributions are expected to be suppressed.

[*hh*] See the "Note on $f_0(1370)$" in the $f_0(1370)$ Particle Listings in the Full *Review of Particle Physics* and in the 1994 edition.

[*ii*] See the note in the $L(1770)$ Particle Listings in Reviews of Modern Physics **56** S1 (1984), p. S200. See also the "Note on $K_2(1770)$ and the $K_2(1820)$" in the $K_2(1770)$ Particle Listings in the Full *Review of Particle Physics*.

[*jj*] See the "Note on $K_2(1770)$ and the $K_2(1820)$" in the $K_2(1770)$ Particle Listings in the Full *Review of Particle Physics*.

[*kk*] This result applies to $Z^0 \to c\overline{c}$ decays only. Here ℓ^+ is an average (not a sum) of e^+ and μ^+ decays.

[*ll*] See the Particle Listings for the (complicated) definition of this quantity.

[*nn*] The branching fraction for this mode may differ from the sum of the submodes that contribute to it, due to interference effects. See the

relevant papers in the Particle Listings in the Full *Review of Particle Physics*.

[*oo*] These subfractions of the $K^- 2\pi^+$ mode are uncertain: see the Particle Listings.

[*pp*] Submodes of the $D^+ \to K^- 2\pi^+ \pi^0$ and $K^0_S 2\pi^+ \pi^-$ modes were studied by ANJOS 92C and COFFMAN 92B, but with at most 142 events for the first mode and 229 for the second – not enough for precise results. With nothing new for 18 years, we refer to our 2008 edition, Physics Letters **B667** 1 (2008), for those results.

[*qq*] The unseen decay modes of the resonances are included.

[*rr*] This is *not* a test for the ΔC=1 weak neutral current, but leads to the $\pi^+ \ell^+ \ell^-$ final state.

[*ss*] This mode is not a useful test for a ΔC=1 weak neutral current because both quarks must change flavor in this decay.

[*tt*] In the 2010 *Review*, the values for these quantities were given using a measure of the asymmetry that was inconsistent with the usual definition.

[*uu*] This value is obtained by subtracting the branching fractions for 2-, 4- and 6-prongs from unity.

[*vv*] This is the sum of our $K^- 2\pi^+ \pi^-$, $K^- 2\pi^+ \pi^- \pi^0$, $\overline{K}^0 2\pi^+ 2\pi^-$, $K^+ 2K^- \pi^+$, $2\pi^+ 2\pi^-$, $2\pi^+ 2\pi^- \pi^0$, $K^+ K^- \pi^+ \pi^-$, and $K^+ K^- \pi^+ \pi^- \pi^0$, branching fractions.

[*xx*] This is the sum of our $K^- 3\pi^+ 2\pi^-$ and $3\pi^+ 3\pi^-$ branching fractions.

[*yy*] The branching fractions for the $K^- e^+ \nu_e$, $K^*(892)^- e^+ \nu_e$, $\pi^- e^+ \nu_e$, and $\rho^- e^+ \nu_e$ modes add up to 6.17 ± 0.17 %.

[*zz*] This is a doubly Cabibbo-suppressed mode.

[*aaa*] Submodes of the $D^0 \to K^0_S \pi^+ \pi^- \pi^0$ mode with a K^* and/or ρ were studied by COFFMAN 92B, but with only 140 events. With nothing new for 18 years, we refer to our 2008 edition, Physics Letters **B667** 1 (2008), for those results.

[*bbb*] This branching fraction includes all the decay modes of the resonance in the final state.

[*ccc*] This limit is for either D^0 or $\overline{D}^0$ to $p e^-$.

[*ddd*] This limit is for either D^0 or $\overline{D}^0$ to $\overline{p} e^+$.

[*eee*] This is the purely e^+ semileptonic branching fraction: the e^+ fraction from τ^+ decays has been subtracted off. The sum of our (non-τ) e^+ exclusive fractions — an $e^+ \nu_e$ with an η, η', ϕ, K^0, or K^{*0} — is 5.99 ± 0.31 %.

[*fff*] This fraction includes η from η' decays.

[*ggg*] The sum of our exclusive η' fractions — $\eta' e^+ \nu_e$, $\eta' \mu^+ \nu_\mu$, $\eta' \pi^+$, $\eta' \rho^+$, and $\eta' K^+$ — is 11.8 ± 1.6%.

[*hhh*] This branching fraction includes all the decay modes of the final-state resonance.

[*iii*] A test for $u\overline{u}$ or $d\overline{d}$ content in the D^+_s. Neither Cabibbo-favored nor Cabibbo-suppressed decays can contribute, and $\omega - \phi$ mixing is an unlikely explanation for any fraction above about 2×10^{-4}.

[*jjj*] We decouple the $D^+_s \to \phi \pi^+$ branching fraction obtained from mass projections (and used to get some of the other branching fractions) from the $D^+_s \to \phi \pi^+$, $\phi \to K^+ K^-$ branching fraction obtained from the Dalitz-plot analysis of $D^+_s \to K^+ K^- \pi^+$. That is, the ratio of

these two branching fractions is not exactly the $\phi \to K^+K^-$ branching fraction 0.491.

[*kkk*] This is the average of a model-independent and a K-matrix parametrization of the $\pi^+\pi^-$ S-wave and is a sum over several f_0 mesons.

[*lll*] An ℓ indicates an e or a μ mode, not a sum over these modes.

[*nnn*] An $CP(\pm1)$ indicates the $CP{=}{+}1$ and $CP{=}{-}1$ eigenstates of the D^0-$\overline{D}^0$ system.

[*ooo*] D denotes D^0 or $\overline{D}^0$.

[*ppp*] D^{*0}_{CP+} decays into $D^0\pi^0$ with the D^0 reconstructed in CP-even eigenstates K^+K^- and $\pi^+\pi^-$.

[*qqq*] $\overline{D}^{**}$ represents an excited state with mass $2.2 < \mathrm{M} < 2.8$ GeV/c^2.

[*rrr*] $\chi_{c1}(3872)^+$ is a hypothetical charged partner of the $\chi_{c1}(3872)$.

[*sss*] $\Theta(1710)^{++}$ is a possible narrow pentaquark state and $G(2220)$ is a possible glueball resonance.

[*ttt*] $(\overline{\Lambda}^-_c p)_s$ denotes a low-mass enhancement near 3.35 GeV/c^2.

[*uuu*] Stands for the possible candidates of $K^*(1410)$, $K^*_0(1430)$ and $K^*_2(1430)$.

[*vvv*] B^0 and B^0_s contributions not separated. Limit is on weighted average of the two decay rates.

[*xxx*] This decay refers to the coherent sum of resonant and nonresonant $J^P = 0^+$ $K\pi$ components with $1.60 < m_{K\pi} < 2.15$ GeV/c^2.

[*yyy*] $X(214)$ is a hypothetical particle of mass 214 MeV/c^2 reported by the HyperCP experiment, Physical Review Letters **94** 021801 (2005)

[*zzz*] $\Theta(1540)^+$ denotes a possible narrow pentaquark state.

[*aaaa*] Here S and P are the hypothetical scalar and pseudoscalar particles with masses of 2.5 GeV/c^2 and 214.3 MeV/c^2, respectively.

[*bbaa*] These values are model dependent.

[*ccaa*] Here "anything" means at least one particle observed.

[*ddaa*] This is a $\mathrm{B}(B^0 \to D^{*-}\ell^+\nu_\ell)$ value.

[*eeaa*] D^{**} stands for the sum of the $D(1\,^1P_1)$, $D(1\,^3P_0)$, $D(1\,^3P_1)$, $D(1\,^3P_2)$, $D(2\,^1S_0)$, and $D(2\,^1S_1)$ resonances.

[*ffaa*] $D^{(*)}\overline{D}^{(*)}$ stands for the sum of $D^*\overline{D}^*$, $D^*\overline{D}$, $D\overline{D}^*$, and $D\overline{D}$.

[*ggaa*] $X(3915)$ denotes a near-threshold enhancement in the $\omega J/\psi$ mass spectrum.

[*hhaa*] Inclusive branching fractions have a multiplicity definition and can be greater than 100%.

[*iiaa*] D_j represents an unresolved mixture of pseudoscalar and tensor D^{**} (P-wave) states.

[*jjaa*] Not a pure measurement. See note at head of B^0_s Decay Modes.

[*kkaa*] For $E_\gamma > 100$ MeV.

[*llaa*] Includes $p\overline{p}\pi^+\pi^-\gamma$ and excludes $p\overline{p}\eta$, $p\overline{p}\omega$, $p\overline{p}\eta'$.

[*nnaa*] See the "Note on the $\eta(1405)$" in the $\eta(1405)$ Particle Listings in the Full *Review of Particle Physics*.

[*ooaa*] For a narrow state A with mass less than 960 MeV.

[*ppaa*] For a narrow scalar or pseudoscalar A^0 with mass 0.21–3.0 GeV.

[*qqaa*] For a narrow resonance in the range $2.2 < M(X) < 2.8$ GeV.

[*rraa*] J^{PC} known by production in $e^+ e^-$ via single photon annihilation. I^G is not known; interpretation of this state as a single resonance is unclear because of the expectation of substantial threshold effects in this energy region.

[*ssaa*] $2m_\tau < \mathrm{M}(\tau^+\tau^-) < 9.2$ GeV

[*ttaa*] 2 GeV $< m_{K^+K^-} <$ 3 GeV

[*uuaa*] X = scalar with $m < 8.0$ GeV

[*vvaa*] $X\overline{X}$ = vectors with $m < 3.1$ GeV

[*xxaa*] X and $\overline{X}$ = zero spin with $m < 4.5$ GeV

[*yyaa*] 1.5 GeV $< m_X <$ 5.0 GeV

[*zzaa*] 201 MeV $< \mathrm{M}(\mu^+\mu^-) <$ 3565 MeV

[*aabb*] 0.5 GeV $< m_X <$ 9.0 GeV, where m_X is the invariant mass of the hadronic final state.

[*bbbb*] Spectroscopic labeling for these states is theoretical, pending experimental information.

[*ccbb*] 1.5 GeV $< m_X <$ 5.0 GeV

[*ddbb*] 1.5 GeV $< m_X <$ 5.0 GeV

[*eebb*] For $m_{\tau^+\tau^-}$ in the ranges 4.03–9.52 and 9.61–10.10 GeV.

N BARYONS
$(S = 0, I = 1/2)$

p, $N^+ = uud$; n, $N^0 = udd$

p

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

Mass $m = 1.00727646662 \pm 0.00000000009$ u (S = 3.1)
Mass $m = 938.272081 \pm 0.000006$ MeV [a]
$|m_p - m_{\overline{p}}|/m_p < 7 \times 10^{-10}$, CL = 90% [b]
$|\frac{q_{\overline{p}}}{m_{\overline{p}}}|/(\frac{q_p}{m_p}) = 1.00000000000 \pm 0.00000000007$
$|q_p + q_{\overline{p}}|/e < 7 \times 10^{-10}$, CL = 90% [b]
$|q_p + q_e|/e < 1 \times 10^{-21}$ [c]
Magnetic moment $\mu = 2.7928473446 \pm 0.0000000008\ \mu_N$
$(\mu_p + \mu_{\overline{p}})\ /\ \mu_p = (0.002 \pm 0.004) \times 10^{-6}$
Electric dipole moment $d < 0.021 \times 10^{-23}$ e cm
Electric polarizability $\alpha = (11.2 \pm 0.4) \times 10^{-4}$ fm^3
Magnetic polarizability $\beta = (2.5 \pm 0.4) \times 10^{-4}$ fm^3 (S = 1.2)
Charge radius, μp Lamb shift $= 0.84087 \pm 0.00039$ fm [d]
Charge radius $= 0.8409 \pm 0.0004$ fm [d]
Magnetic radius $= 0.851 \pm 0.026$ fm [e]
Mean life $\tau > 3.6 \times 10^{29}$ years, CL = 90% [f] ($p \rightarrow$ invisible mode)
Mean life $\tau > 10^{31}$ to 10^{33} years [f] (mode dependent)

See the "Note on Nucleon Decay" in our 1994 edition (Phys. Rev. **D50**, 1173) for a short review.

The "partial mean life" limits tabulated here are the limits on τ/B_i, where τ is the total mean life and B_i is the branching fraction for the mode in question. For N decays, p and n indicate proton and neutron partial lifetimes.

p DECAY MODES	Partial mean life (10^{30} years)	Confidence level	p (MeV/c)
	Antilepton + meson		
$N \rightarrow e^+\pi$	> 5300 (n), > 16000 (p)	90%	459
$N \rightarrow \mu^+\pi$	> 3500 (n), > 7700 (p)	90%	453
$N \rightarrow \nu\pi$	> 1100 (n), > 390 (p)	90%	459
$p \rightarrow e^+\eta$	> 10000	90%	309
$p \rightarrow \mu^+\eta$	> 4700	90%	297
$n \rightarrow \nu\eta$	> 158	90%	310
$N \rightarrow e^+\rho$	> 217 (n), > 720 (p)	90%	149
$N \rightarrow \mu^+\rho$	> 228 (n), > 570 (p)	90%	113
$N \rightarrow \nu\rho$	> 19 (n), > 162 (p)	90%	149
$p \rightarrow e^+\omega$	> 1600	90%	143
$p \rightarrow \mu^+\omega$	> 2800	90%	105
$n \rightarrow \nu\omega$	> 108	90%	144
$N \rightarrow e^+K$	> 17 (n), > 1000 (p)	90%	339
$N \rightarrow \mu^+K$	> 26 (n), > 1600 (p)	90%	329
$N \rightarrow \nu K$	> 86 (n), > 5900 (p)	90%	339
$n \rightarrow \nu K^0_S$	> 260	90%	338
$p \rightarrow e^+K^*(892)^0$	> 84	90%	45
$N \rightarrow \nu K^*(892)$	> 78 (n), > 51 (p)	90%	45

Antilepton + mesons			
$p \to e^+ \pi^+ \pi^-$	> 82	90%	448
$p \to e^+ \pi^0 \pi^0$	> 147	90%	449
$n \to e^+ \pi^- \pi^0$	> 52	90%	449
$p \to \mu^+ \pi^+ \pi^-$	> 133	90%	425
$p \to \mu^+ \pi^0 \pi^0$	> 101	90%	427
$n \to \mu^+ \pi^- \pi^0$	> 74	90%	427
$n \to e^+ K^0 \pi^-$	> 18	90%	319
Lepton + meson			
$n \to e^- \pi^+$	> 65	90%	459
$n \to \mu^- \pi^+$	> 49	90%	453
$n \to e^- \rho^+$	> 62	90%	150
$n \to \mu^- \rho^+$	> 7	90%	115
$n \to e^- K^+$	> 32	90%	340
$n \to \mu^- K^+$	> 57	90%	330
Lepton + mesons			
$p \to e^- \pi^+ \pi^+$	> 30	90%	448
$n \to e^- \pi^+ \pi^0$	> 29	90%	449
$p \to \mu^- \pi^+ \pi^+$	> 17	90%	425
$n \to \mu^- \pi^+ \pi^0$	> 34	90%	427
$p \to e^- \pi^+ K^+$	> 75	90%	320
$p \to \mu^- \pi^+ K^+$	> 245	90%	279
Antilepton + photon(s)			
$p \to e^+ \gamma$	> 670	90%	469
$p \to \mu^+ \gamma$	> 478	90%	463
$n \to \nu \gamma$	> 550	90%	470
$p \to e^+ \gamma \gamma$	> 100	90%	469
$n \to \nu \gamma \gamma$	> 219	90%	470
Antilepton + single massless			
$p \to e^+ X$	> 790	90%	–
$p \to \mu^+ X$	> 410	90%	–
Three (or more) leptons			
$p \to e^+ e^+ e^-$	> 793	90%	469
$p \to e^+ \mu^+ \mu^-$	> 359	90%	457
$p \to e^+ \nu \nu$	> 170	90%	469
$n \to e^+ e^- \nu$	> 257	90%	470
$n \to \mu^+ e^- \nu$	> 83	90%	464
$n \to \mu^+ \mu^- \nu$	> 79	90%	458
$p \to \mu^+ e^+ e^-$	> 529	90%	463
$p \to \mu^+ \mu^+ \mu^-$	> 675	90%	439
$p \to \mu^+ \nu \nu$	> 220	90%	463
$p \to e^- \mu^+ \mu^+$	> 6	90%	457
$n \to 3\nu$	$> 5 \times 10^{-4}$	90%	470
Inclusive modes			
$N \to e^+$ anything	> 0.6 (n, p)	90%	–
$N \to \mu^+$ anything	> 12 (n, p)	90%	–
$N \to e^+ \pi^0$ anything	> 0.6 (n, p)	90%	–
$\Delta B = 2$ dinucleon modes			
The following are lifetime limits per iron nucleus.			
$p p \to \pi^+ \pi^+$	> 72.2	90%	–
$p n \to \pi^+ \pi^0$	> 170	90%	–

$n n \rightarrow \pi^+ \pi^-$	> 0.7	90%	–
$n n \rightarrow \pi^0 \pi^0$	> 404	90%	–
$p p \rightarrow K^+ K^+$	> 170	90%	–
$p p \rightarrow e^+ e^+$	> 5.8	90%	–
$p p \rightarrow e^+ \mu^+$	> 3.6	90%	–
$p p \rightarrow \mu^+ \mu^+$	> 1.7	90%	–
$p n \rightarrow e^+ \overline{\nu}$	> 260	90%	–
$p n \rightarrow \mu^+ \overline{\nu}$	> 200	90%	–
$p n \rightarrow \tau^+ \overline{\nu}_\tau$	> 29	90%	–
$n n \rightarrow \nu_e \overline{\nu}_e$	> 1.4	90%	–
$n n \rightarrow \nu_\mu \overline{\nu}_\mu$	> 1.4	90%	–
$p n \rightarrow$ invisible	$> 2.1 \times 10^{-5}$	90%	–
$p p \rightarrow$ invisible	$> 5 \times 10^{-5}$	90%	–

$\overline{p}$ DECAY MODES

Mode	Partial mean life (years)	Confidence level	p (MeV/c)
$\overline{p} \rightarrow e^- \gamma$	$> 7 \times 10^5$	90%	469
$\overline{p} \rightarrow \mu^- \gamma$	$> 5 \times 10^4$	90%	463
$\overline{p} \rightarrow e^- \pi^0$	$> 4 \times 10^5$	90%	459
$\overline{p} \rightarrow \mu^- \pi^0$	$> 5 \times 10^4$	90%	453
$\overline{p} \rightarrow e^- \eta$	$> 2 \times 10^4$	90%	309
$\overline{p} \rightarrow \mu^- \eta$	$> 8 \times 10^3$	90%	297
$\overline{p} \rightarrow e^- K^0_S$	> 900	90%	337
$\overline{p} \rightarrow \mu^- K^0_S$	$> 4 \times 10^3$	90%	326
$\overline{p} \rightarrow e^- K^0_L$	$> 9 \times 10^3$	90%	337
$\overline{p} \rightarrow \mu^- K^0_L$	$> 7 \times 10^3$	90%	326
$\overline{p} \rightarrow e^- \gamma\gamma$	$> 2 \times 10^4$	90%	469
$\overline{p} \rightarrow \mu^- \gamma\gamma$	$> 2 \times 10^4$	90%	463
$\overline{p} \rightarrow e^- \omega$	> 200	90%	143

n

$$I(J^P) = \tfrac{1}{2}(\tfrac{1}{2}^+)$$

Mass $m = 1.0086649159 \pm 0.0000000005$ u

Mass $m = 939.565413 \pm 0.000006$ MeV [a]

$(m_n - m_{\overline{n}})/\ m_n = (9 \pm 6) \times 10^{-5}$

$m_n - m_p = 1.2933321 \pm 0.0000005$ MeV

$= 0.00138844919(45)$ u

Mean life $\tau = 879.4 \pm 0.6$ s (S = 1.6)

$c\tau = 2.6362 \times 10^8$ km

Magnetic moment $\mu = -1.9130427 \pm 0.0000005\ \mu_N$

Electric dipole moment $d < 0.18 \times 10^{-25}$ e cm, CL = 90%

Mean-square charge radius $\langle r_n^2 \rangle = -0.1161 \pm 0.0022$ fm^2 (S = 1.3)

Magnetic radius $\sqrt{\langle r_M^2 \rangle} = 0.864^{+0.009}_{-0.008}$ fm

Electric polarizability $\alpha = (11.8 \pm 1.1) \times 10^{-4}$ fm^3

Magnetic polarizability $\beta = (3.7 \pm 1.2) \times 10^{-4}$ fm^3

Charge $q = (-0.2 \pm 0.8) \times 10^{-21}$ e

Mean $n\overline{n}$-oscillation time $> 8.6 \times 10^7$ s, CL = 90% (free n)

Mean $n\overline{n}$-oscillation time $> 2.7 \times 10^8$ s, CL = 90% [g] (bound n)

Mean $n n'$-oscillation time > 448 s, CL = 90% [h]

$pe^-\nu_e$ decay parameters [i]

$\lambda \equiv g_A \,/\, g_V = -1.2756 \pm 0.0013$ (S = 2.6)
$A = -0.11958 \pm 0.00021$ (S = 1.2)
$B = 0.9807 \pm 0.0030$
$C = -0.2377 \pm 0.0026$
$a = -0.1059 \pm 0.0028$
$\phi_{AV} = (180.017 \pm 0.026)^\circ$ [j]
$D = (-1.2 \pm 2.0) \times 10^{-4}$ [k]
$R = 0.004 \pm 0.013$ [k]

n DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$pe^-\overline{\nu}_e$		100 %		1
$pe^-\overline{\nu}_e\gamma$	[l]	(9.2±0.7) × 10^{-3}		1
hydrogen-atom $\overline{\nu}_e$		< 2.7 × 10^{-3}	95%	1.19
Charge conservation (Q) violating mode				
$p\nu_e\overline{\nu}_e$	Q	< 8 × 10^{-27}	68%	1

N(1440) 1/2$^+$

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

Re(pole position) = 1360 to 1380 (≈ 1370) MeV
−2Im(pole position) = 160 to 190 (≈ 175) MeV
Breit-Wigner mass = 1410 to 1470 (≈ 1440) MeV
Breit-Wigner full width = 250 to 450 (≈ 350) MeV

The following branching fractions are our estimates, not fits or averages.

N(1440) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	55–75 %	398
$N\eta$	<1 %	†
$N\pi\pi$	17–50 %	347
$\Delta(1232)\pi$, P-wave	6–27 %	147
$N\sigma$	11–23 %	–
$p\gamma$, helicity=1/2	0.035–0.048 %	414
$n\gamma$, helicity=1/2	0.02–0.04 %	413

N(1520) 3/2$^-$

$I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$

Re(pole position) = 1505 to 1515 (≈ 1510) MeV
−2Im(pole position) = 105 to 120 (≈ 110) MeV
Breit-Wigner mass = 1510 to 1520 (≈ 1515) MeV
Breit-Wigner full width = 100 to 120 (≈ 110) MeV

The following branching fractions are our estimates, not fits or averages.

N(1520) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	55–65 %	453
$N\eta$	0.07–0.09 %	142
$N\pi\pi$	25–35 %	410
$\Delta(1232)\pi$	22–34 %	225
$\Delta(1232)\pi$, S-wave	15–23 %	225
$\Delta(1232)\pi$, D-wave	7–11 %	225

$N\sigma$	$<$ 2 %	–
$p\gamma$	0.31–0.52 %	467
$p\gamma$, helicity=1/2	0.01–0.02 %	467
$p\gamma$, helicity=3/2	0.30–0.50 %	467
$n\gamma$	0.30–0.53 %	466
$n\gamma$, helicity=1/2	0.04–0.10 %	466
$n\gamma$, helicity=3/2	0.25–0.45 %	466

$N(1535)\ 1/2^-$

$I(J^P) = \frac{1}{2}(\frac{1}{2}^-)$

Re(pole position) = 1500 to 1520 ($\approx$ 1510) MeV
-2Im(pole position) = 110 to 150 ($\approx$ 130) MeV
Breit-Wigner mass = 1515 to 1545 ($\approx$ 1530) MeV
Breit-Wigner full width = 125 to 175 ($\approx$ 150) MeV

The following branching fractions are our estimates, not fits or averages.

***N*(1535) DECAY MODES**	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	32–52 %	464
$N\eta$	30–55 %	176
$N\pi\pi$	3–14 %	422
$\Delta(1232)\pi$, D-wave	1–4 %	240
$N\sigma$	2–10 %	–
$N(1440)\pi$	5–12 %	†
$p\gamma$, helicity=1/2	0.15–0.30 %	477
$n\gamma$, helicity=1/2	0.01–0.25 %	477

$N(1650)\ 1/2^-$, $N(1675)\ 5/2^-$, $N(1680)\ 5/2^+$, $N(1700)\ 3/2^-$, $N(1710)\ 1/2^+$, $N(1720)\ 3/2^+$, $N(1875)\ 3/2^-$, $N(1880)\ 1/2^+$, $N(1895)\ 1/2^-$, $N(1900)\ 3/2^+$ $N(2060)\ 5/2^-$, $N(2100)\ 1/2^+$, $N(2120)\ 3/2^-$, $N(2190)\ 7/2^-$, $N(2220)\ 9/2^+$ $N(2250)\ 9/2^-$, $N(2600)\ 11/2^-$

The N resonances listed above are omitted from this Booklet but not from the Summary Table in the full *Review*.

Δ BARYONS
($S = 0$, $I = 3/2$)

$\Delta^{++} = uuu$, $\Delta^{+} = uud$, $\Delta^{0} = udd$, $\Delta^{-} = ddd$

$\Delta(1232)\ 3/2^+$

$I(J^P) = \frac{3}{2}(\frac{3}{2}^+)$

Re(pole position) = 1209 to 1211 ($\approx$ 1210) MeV
-2Im(pole position) = 98 to 102 ($\approx$ 100) MeV
Breit-Wigner mass (mixed charges) = 1230 to 1234 ($\approx$ 1232) MeV
Breit-Wigner full width (mixed charges) = 114 to 120 ($\approx$ 117) MeV

The following branching fractions are our estimates, not fits or averages.

Δ(1232) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	99.4 %	229
$N\gamma$	0.55–0.65 %	259
$N\gamma$, helicity=1/2	0.11–0.13 %	259
$N\gamma$, helicity=3/2	0.44–0.52 %	259
$p e^+ e^-$	(4.2±0.7) $\times 10^{-5}$	259

Δ(1600) $3/2^+$

$I(J^P) = \frac{3}{2}(\frac{3}{2}^+)$

Re(pole position) = 1460 to 1560 (≈ 1510) MeV
−2Im(pole position) = 200 to 340 (≈ 270) MeV
Breit-Wigner mass = 1500 to 1640 (≈ 1570) MeV
Breit-Wigner full width = 200 to 300 (≈ 250) MeV

The following branching fractions are our estimates, not fits or averages.

Δ(1600) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	8–24 %	492
$N\pi\pi$	75–90 %	454
$\Delta(1232)\pi$	73–83 %	276
$\Delta(1232)\pi$, P-wave	72–82 %	276
$\Delta(1232)\pi$, F-wave	<2 %	276
$N(1440)\pi$, P-wave	15–25 %	†
$N\gamma$	0.001–0.035 %	505
$N\gamma$, helicity=1/2	0.0–0.02 %	505
$N\gamma$, helicity=3/2	0.001–0.015 %	505

Δ(1620) $1/2^-$

$I(J^P) = \frac{3}{2}(\frac{1}{2}^-)$

Re(pole position) = 1590 to 1610 (≈ 1600) MeV
−2Im(pole position) = 100 to 140 (≈ 120) MeV
Breit-Wigner mass = 1590 to 1630 (≈ 1610) MeV
Breit-Wigner full width = 110 to 150 (≈ 130) MeV

The following branching fractions are our estimates, not fits or averages.

Δ(1620) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	25–35 %	520
$N\pi\pi$	55–80 %	484
$\Delta(1232)\pi$, D-wave	52–72 %	311
$N(1440)\pi$	3–9 %	98
$N\gamma$, helicity=1/2	0.03–0.10 %	532

See Particle Listings for 2 decay modes that have been seen / not seen.

Δ(1700) $3/2^-$, Δ(1900) $1/2^-$, Δ(1905) $5/2^+$, Δ(1910) $1/2^+$, Δ(1920) $3/2^+$, Δ(1930) $5/2^-$, Δ(1950) $7/2^+$, Δ(2200) $7/2^-$, Δ(2420) $11/2^+$

The Δ resonances listed above are omitted from this Booklet but not from the Summary Table in the full *Review*.

Λ BARYONS
$(S=-1, I=0)$

$\Lambda^0 = uds$

Λ

$I(J^P) = 0(\frac{1}{2}^+)$

Mass $m = 1115.683 \pm 0.006$ MeV
$(m_\Lambda - m_{\overline{\Lambda}}) \,/\, m_\Lambda = (-0.1 \pm 1.1) \times 10^{-5}$ (S = 1.6)
Mean life $\tau = (2.632 \pm 0.020) \times 10^{-10}$ s (S = 1.6)
$(\tau_\Lambda - \tau_{\overline{\Lambda}}) \,/\, \tau_\Lambda = -0.001 \pm 0.009$
$c\tau = 7.89$ cm
Magnetic moment $\mu = -0.613 \pm 0.004\ \mu_N$
Electric dipole moment $d < 1.5 \times 10^{-16}$ e cm, CL = 95%

Decay parameters

$p\pi^-$ $\alpha_- = 0.732 \pm 0.014$ (S = 2.3)
$\overline{p}\pi^+$ $\alpha_+ = -0.758 \pm 0.012$
$\overline{\alpha}_0$ FOR $\overline{\Lambda} \to \overline{n}\pi^0 = -0.692 \pm 0.017$
$p\pi^-$ $\phi_- = (-6.5 \pm 3.5)^\circ$
" $\gamma_- = 0.76$ [n]
" $\Delta_- = (8 \pm 4)^\circ$ [n]
$\overline{\alpha}_0 \,/\, \alpha_+$ in $\overline{\Lambda} \to \overline{n}\pi^0$, $\overline{\Lambda} \to \overline{p}\pi^+ = 0.913 \pm 0.030$
$R = |G_E/G_M|$ in $\Lambda \to p\pi^-$, $\overline{\Lambda} \to \overline{p}\pi^+ = 0.96 \pm 0.14$
$\Delta\Phi = \Phi_E - \Phi_M$ in $\Lambda \to p\pi^-$, $\overline{\Lambda} \to \overline{p}\pi^+ = 37 \pm 13$ degrees
$n\pi^0$ $\alpha_0 = 0.74 \pm 0.05$
$pe^-\overline{\nu}_e$ $g_A/g_V = -0.718 \pm 0.015$ [i]

Λ DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$p\pi^-$		(63.9 ± 0.5) %		101
$n\pi^0$		(35.8 ± 0.5) %		104
$n\gamma$		$(1.75 \pm 0.15) \times 10^{-3}$		162
$p\pi^-\gamma$	[o]	$(8.4 \pm 1.4) \times 10^{-4}$		101
$pe^-\overline{\nu}_e$		$(8.32 \pm 0.14) \times 10^{-4}$		163
$p\mu^-\overline{\nu}_\mu$		$(1.57 \pm 0.35) \times 10^{-4}$		131
Lepton (L) and/or Baryon (B) number violating decay modes				
π^+e^-	L,B	$< 6 \times 10^{-7}$	90%	549
$\pi^+\mu^-$	L,B	$< 6 \times 10^{-7}$	90%	544
π^-e^+	L,B	$< 4 \times 10^{-7}$	90%	549
$\pi^-\mu^+$	L,B	$< 6 \times 10^{-7}$	90%	544
K^+e^-	L,B	$< 2 \times 10^{-6}$	90%	449
$K^+\mu^-$	L,B	$< 3 \times 10^{-6}$	90%	441
K^-e^+	L,B	$< 2 \times 10^{-6}$	90%	449
$K^-\mu^+$	L,B	$< 3 \times 10^{-6}$	90%	441
$K^0_S\nu$	L,B	$< 2 \times 10^{-5}$	90%	447
$\overline{p}\pi^+$	B	$< 9 \times 10^{-7}$	90%	101

$\Lambda(1405)$ 1/2$^-$

$I(J^P) = 0(\frac{1}{2}^-)$

Mass $m = 1405.1^{+1.3}_{-1.0}$ MeV
Full width $\Gamma = 50.5 \pm 2.0$ MeV
Below $\overline{K}N$ threshold

$\Lambda(1405)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Sigma\pi$	100 %	155

$\Lambda(1520)$ 3/2$^-$

$I(J^P) = 0(\frac{3}{2}^-)$

Mass m = 1518 to 1520 ($\approx$ 1519) MeV [p]
Full width Γ = 15 to 17 ($\approx$ 16) MeV [p]

$\Lambda(1520)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	(45 ± 1) %	242
$\Sigma\pi$	(42 ± 1) %	268
$\Lambda\pi\pi$	(10 ± 1) %	259
$\Sigma\pi\pi$	(0.9 ± 0.1) %	168
$\Lambda\gamma$	(0.85 ± 0.15) %	350

$\Lambda(1600)$ 1/2$^+$, $\Lambda(1670)$ 1/2$^-$, $\Lambda(1690)$ 3/2$^-$, $\Lambda(1800)$ 1/2$^-$, $\Lambda(1810)$ 1/2$^+$, $\Lambda(1820)$ 5/2$^+$, $\Lambda(1830)$ 5/2$^-$, $\Lambda(1890)$ 3/2$^+$, $\Lambda(2100)$ 7/2$^-$, $\Lambda(2110)$ 5/2$^+$, $\Lambda(2350)$ 9/2$^+$

The Λ resonances listed above are omitted from this Booklet but not from the Summary Table in the full *Review*.

Σ BARYONS
($S=-1, I=1$)

$\Sigma^+ = uus, \quad \Sigma^0 = uds, \quad \Sigma^- = dds$

Σ^+

$I(J^P) = 1(\frac{1}{2}^+)$

Mass $m = 1189.37 \pm 0.07$ MeV (S = 2.2)
Mean life $\tau = (0.8018 \pm 0.0026) \times 10^{-10}$ s
$c\tau = 2.404$ cm
$(\tau_{\Sigma^+} - \tau_{\overline{\Sigma}^-}) / \tau_{\Sigma^+} = -0.0006 \pm 0.0012$
Magnetic moment $\mu = 2.458 \pm 0.010\ \mu_N$ (S = 2.1)
$(\mu_{\Sigma^+} + \mu_{\overline{\Sigma}^-}) / \mu_{\Sigma^+} = 0.014 \pm 0.015$
$\Gamma(\Sigma^+ \to n\ell^+\nu)/\Gamma(\Sigma^- \to n\ell^-\overline{\nu}) < 0.043$

Decay parameters

$p\pi^0$	$\alpha_0 = -0.980^{+0.017}_{-0.015}$
"	$\phi_0 = (36 \pm 34)^\circ$
"	$\gamma_0 = 0.16$ [n]
"	$\Delta_0 = (187 \pm 6)^\circ$ [n]

$n\pi^+$	$\alpha_+ = 0.068 \pm 0.013$
"	$\phi_+ = (167 \pm 20)^\circ$ (S = 1.1)
"	$\gamma_+ = -0.97$ [n]
"	$\Delta_+ = (-73^{+133}_{-10})^\circ$ [n]
$p\gamma$	$\alpha_\gamma = -0.76 \pm 0.08$

Σ^+ DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$p\pi^0$		(51.57 ± 0.30) %		189
$n\pi^+$		(48.31 ± 0.30) %		185
$p\gamma$		$(1.23\pm0.05)\times10^{-3}$		225
$n\pi^+\gamma$	[o]	$(4.5\pm0.5)\times10^{-4}$		185
$\Lambda e^+\nu_e$		$(2.0\pm0.5)\times10^{-5}$		71
$\Delta S = \Delta Q$ (SQ) violating modes or $\Delta S = 1$ weak neutral current ($S1$) modes				
$n e^+\nu_e$	SQ	$< 5 \times10^{-6}$	90%	224
$n\mu^+\nu_\mu$	SQ	$< 3.0 \times10^{-5}$	90%	202
$p e^+ e^-$	$S1$	$< 7 \times10^{-6}$		225
$p\mu^+\mu^-$	$S1$	$(2.4\ ^{+1.7}_{-1.3})\times10^{-8}$		121

Σ^0

$I(J^P) = 1(\frac{1}{2}^+)$

Mass $m = 1192.642 \pm 0.024$ MeV
$m_{\Sigma^-} - m_{\Sigma^0} = 4.807 \pm 0.035$ MeV (S = 1.1)
$m_{\Sigma^0} - m_\Lambda = 76.959 \pm 0.023$ MeV
Mean life $\tau = (7.4 \pm 0.7) \times 10^{-20}$ s
$c\tau = 2.22 \times 10^{-11}$ m
Transition magnetic moment $|\mu_{\Sigma\Lambda}| = 1.61 \pm 0.08\ \mu_N$

Σ^0 DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\Lambda\gamma$		100 %		74
$\Lambda\gamma\gamma$		$<$ 3 %	90%	74
$\Lambda e^+ e^-$	[q]	5×10^{-3}		74

Σ^-

$I(J^P) = 1(\frac{1}{2}^+)$

Mass $m = 1197.449 \pm 0.030$ MeV (S = 1.2)
$m_{\Sigma^-} - m_{\Sigma^+} = 8.08 \pm 0.08$ MeV (S = 1.9)
$m_{\Sigma^-} - m_\Lambda = 81.766 \pm 0.030$ MeV (S = 1.2)
Mean life $\tau = (1.479 \pm 0.011) \times 10^{-10}$ s (S = 1.3)
$c\tau = 4.434$ cm
Magnetic moment $\mu = -1.160 \pm 0.025\ \mu_N$ (S = 1.7)
Σ^- charge radius $= 0.78 \pm 0.10$ fm

Decay parameters

$n\pi^-$	$\alpha_- = -0.068 \pm 0.008$
"	$\phi_- = (10 \pm 15)^\circ$
"	$\gamma_- = 0.98$ [n]
"	$\Delta_- = (249^{+12}_{-120})^\circ$ [n]

$ne^-\overline{\nu}_e$	$g_A/g_V = 0.340 \pm 0.017$ [i]
"	$f_2(0)/f_1(0) = 0.97 \pm 0.14$
"	$D = 0.11 \pm 0.10$
$\Lambda e^-\overline{\nu}_e$	$g_V/g_A = 0.01 \pm 0.10$ [i] (S = 1.5)
"	$g_{WM}/g_A = 2.4 \pm 1.7$ [i]

Σ^- DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$n\pi^-$	(99.848 ± 0.005) %	193
$n\pi^-\gamma$	[o] $(4.6 \pm 0.6) \times 10^{-4}$	193
$ne^-\overline{\nu}_e$	$(1.017 \pm 0.034) \times 10^{-3}$	230
$n\mu^-\overline{\nu}_\mu$	$(4.5 \pm 0.4) \times 10^{-4}$	210
$\Lambda e^-\overline{\nu}_e$	$(5.73 \pm 0.27) \times 10^{-5}$	79

$\Sigma(1385)$ 3/2$^+$

$I(J^P) = 1(\frac{3}{2}^+)$

$\Sigma(1385)^+$ mass $m = 1382.80 \pm 0.35$ MeV (S = 1.9)
$\Sigma(1385)^0$ mass $m = 1383.7 \pm 1.0$ MeV (S = 1.4)
$\Sigma(1385)^-$ mass $m = 1387.2 \pm 0.5$ MeV (S = 2.2)
$\Sigma(1385)^+$ full width $\Gamma = 36.0 \pm 0.7$ MeV
$\Sigma(1385)^0$ full width $\Gamma = 36 \pm 5$ MeV
$\Sigma(1385)^-$ full width $\Gamma = 39.4 \pm 2.1$ MeV (S = 1.7)
Below $\overline{K}N$ threshold

$\Sigma(1385)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\Lambda\pi$	(87.0 ± 1.5) %		208
$\Sigma\pi$	(11.7 ± 1.5) %		129
$\Lambda\gamma$	$(1.25^{+0.13}_{-0.12})$ %		241
$\Sigma^+\gamma$	$(7.0 \pm 1.7) \times 10^{-3}$		180
$\Sigma^-\gamma$	$< 2.4 \times 10^{-4}$	90%	173

$\Sigma(1660)$ 1/2$^+$

$I(J^P) = 1(\frac{1}{2}^+)$

Re(pole position) = 1585 ± 20 MeV
-2Im(pole position) = 290^{+140}_{-40} MeV
Mass m = 1640 to 1680 ($\approx$ 1660) MeV
Full width Γ = 100 to 300 ($\approx$ 200) MeV

$\Sigma(1660)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	0.05 to 0.15 ($\approx$ 010)	405
$\Lambda\pi$	(35 ± 12) %	440
$\Sigma\pi$	(37 ± 10) %	387
$\Sigma\sigma$	(20 ± 8) %	–
$\Lambda(1405)\pi$	(4.0 ± 2.0) %	199

$\Sigma(1670)$ 3/2$^-$, $\Sigma(1750)$ 1/2$^-$, $\Sigma(1775)$ 5/2$^-$, $\Sigma(1915)$ 5/2$^+$, $\Sigma(1940)$ 3/2$^-$, $\Sigma(2030)$ 7/2$^+$, $\Sigma(2250)$

The Σ resonances listed above are omitted from this Booklet but not from the Summary Table in the full *Review*.

Ξ BARYONS
$(S=-2, I=1/2)$

$\Xi^0 = uss, \quad \Xi^- = dss$

Ξ^0

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

P is not yet measured; + is the quark model prediction.

Mass $m = 1314.86 \pm 0.20$ MeV
$m_{\Xi^-} - m_{\Xi^0} = 6.85 \pm 0.21$ MeV
Mean life $\tau = (2.90 \pm 0.09) \times 10^{-10}$ s
$c\tau = 8.71$ cm
Magnetic moment $\mu = -1.250 \pm 0.014\ \mu_N$

Decay parameters

$\Lambda\pi^0$	$\alpha = -0.356 \pm 0.011$
"	$\phi = (21 \pm 12)^\circ$
"	$\gamma = 0.85$ [n]
"	$\Delta = (218^{+12}_{-19})^\circ$ [n]
$\Lambda\gamma$	$\alpha = -0.70 \pm 0.07$
$\Lambda e^+ e^-$	$\alpha = -0.8 \pm 0.2$
$\Sigma^0\gamma$	$\alpha = -0.69 \pm 0.06$
$\Sigma^+ e^- \overline{\nu}_e$	$g_1(0)/f_1(0) = 1.22 \pm 0.05$
$\Sigma^+ e^- \overline{\nu}_e$	$f_2(0)/f_1(0) = 2.0 \pm 0.9$

Ξ^0 DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\Lambda\pi^0$		(99.524 ± 0.012) %		135
$\Lambda\gamma$		$(1.17 \pm0.07) \times 10^{-3}$		184
$\Lambda e^+ e^-$		$(7.6 \pm0.6) \times 10^{-6}$		184
$\Sigma^0\gamma$		$(3.33 \pm0.10) \times 10^{-3}$		117
$\Sigma^+ e^- \overline{\nu}_e$		$(2.52 \pm0.08) \times 10^{-4}$		120
$\Sigma^+ \mu^- \overline{\nu}_\mu$		$(2.33 \pm0.35) \times 10^{-6}$		64
$\Delta S = \Delta Q$ (SQ) violating modes or $\Delta S = 2$ forbidden ($S2$) modes				
$\Sigma^- e^+ \nu_e$	SQ	$< 9 \times 10^{-4}$	90%	112
$\Sigma^- \mu^+ \nu_\mu$	SQ	$< 9 \times 10^{-4}$	90%	49
$p\pi^-$	$S2$	$< 8 \times 10^{-6}$	90%	299
$p e^- \overline{\nu}_e$	$S2$	$< 1.3 \times 10^{-3}$		323
$p \mu^- \overline{\nu}_\mu$	$S2$	$< 1.3 \times 10^{-3}$		309

Ξ^-

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

P is not yet measured; + is the quark model prediction.

Mass $m = 1321.71 \pm 0.07$ MeV
$(m_{\Xi^-} - m_{\Xi^+}) / m_{\Xi^-} = (-3 \pm 9) \times 10^{-5}$
Mean life $\tau = (1.639 \pm 0.015) \times 10^{-10}$ s
$c\tau = 4.91$ cm
$(\tau_{\Xi^-} - \tau_{\Xi^+}) / \tau_{\Xi^-} = -0.01 \pm 0.07$
Magnetic moment $\mu = -0.6507 \pm 0.0025\ \mu_N$
$(\mu_{\Xi^-} + \mu_{\Xi^+}) / |\mu_{\Xi^-}| = +0.01 \pm 0.05$

Decay parameters

$\Lambda\pi^-$ $\alpha = -0.401 \pm 0.010$

$[\alpha(\Xi^-)\alpha_-(\Lambda) - \alpha(\overline{\Xi}^+)\alpha_+(\overline{\Lambda})]$ / [sum] $= (0 \pm 7) \times 10^{-4}$

" $\phi = (-2.1 \pm 0.8)^\circ$

" $\gamma = 0.89$ [n]

" $\Delta = (175.9 \pm 1.5)^\circ$ [n]

$\Lambda e^- \overline{\nu}_e$ $g_A/g_V = -0.25 \pm 0.05$ [i]

Ξ^- DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\Lambda\pi^-$		(99.887 ± 0.035) %		140
$\Sigma^-\gamma$		$(1.27 \pm0.23) \times 10^{-4}$		118
$\Lambda e^-\overline{\nu}_e$		$(5.63 \pm0.31) \times 10^{-4}$		190
$\Lambda\mu^-\overline{\nu}_\mu$		$(3.5 {}^{+3.5}_{-2.2}) \times 10^{-4}$		163
$\Sigma^0 e^-\overline{\nu}_e$		$(8.7 \pm1.7) \times 10^{-5}$		123
$\Sigma^0 \mu^-\overline{\nu}_\mu$		$< 8 \times 10^{-4}$	90%	70
$\Xi^0 e^-\overline{\nu}_e$		$< 2.3 \times 10^{-3}$	90%	7
$\Delta S = 2$ forbidden ($S2$) modes				
$n\pi^-$	$S2$	$< 1.9 \times 10^{-5}$	90%	304
$ne^-\overline{\nu}_e$	$S2$	$< 3.2 \times 10^{-3}$	90%	327
$n\mu^-\overline{\nu}_\mu$	$S2$	< 1.5 %	90%	314
$p\pi^-\pi^-$	$S2$	$< 4 \times 10^{-4}$	90%	223
$p\pi^- e^-\overline{\nu}_e$	$S2$	$< 4 \times 10^{-4}$	90%	305
$p\pi^-\mu^-\overline{\nu}_\mu$	$S2$	$< 4 \times 10^{-4}$	90%	251
$p\mu^-\mu^-$	L	$< 4 \times 10^{-8}$	90%	272

$\Xi(1530)$ 3/2$^+$

$I(J^P) = \frac{1}{2}(\frac{3}{2}^+)$

$\Xi(1530)^0$ mass $m = 1531.80 \pm 0.32$ MeV (S = 1.3)

$\Xi(1530)^-$ mass $m = 1535.0 \pm 0.6$ MeV

$\Xi(1530)^0$ full width $\Gamma = 9.1 \pm 0.5$ MeV

$\Xi(1530)^-$ full width $\Gamma = 9.9^{+1.7}_{-1.9}$ MeV

$\Xi(1530)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\Xi\pi$	100 %		158
$\Xi\gamma$	<3.7 %	90%	202

$\Xi(1690)$, $\Xi(1820)$ 3/2$^-$, $\Xi(1950)$, $\Xi(2030)$

The Ξ resonances listed above are omitted from this Booklet but not from the Summary Table in the full *Review*.

Ω BARYONS
$(S=-3, I=0)$

$\Omega^- = sss$

Ω^-

$I(J^P) = 0(\frac{3}{2}^+)$

$J^P = \frac{3}{2}^+$ is the quark-model prediction; and $J = 3/2$ is fairly well established.

Mass $m = 1672.45 \pm 0.29$ MeV
$(m_{\Omega^-} - m_{\overline{\Omega}^+}) \ / \ m_{\Omega^-} = (-1 \pm 8) \times 10^{-5}$
Mean life $\tau = (0.821 \pm 0.011) \times 10^{-10}$ s
$c\tau = 2.461$ cm
$(\tau_{\Omega^-} - \tau_{\overline{\Omega}^+}) \ / \ \tau_{\Omega^-} = 0.00 \pm 0.05$
Magnetic moment $\mu = -2.02 \pm 0.05 \ \mu_N$

Decay parameters

$\alpha(\Omega^-) \ \alpha_-(\Lambda)$ FOR $\Omega^- \to \Lambda K^- = 0.0115 \pm 0.0015$
ΛK^- $\alpha = 0.0157 \pm 0.0021$
$\Lambda K^-, \overline{\Lambda} K^+$ $(\alpha + \overline{\alpha})/(\alpha - \overline{\alpha}) = -0.02 \pm 0.13$
$\Xi^0 \pi^-$ $\alpha = 0.09 \pm 0.14$
$\Xi^- \pi^0$ $\alpha = 0.05 \pm 0.21$

Ω^- DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
ΛK^-		(67.8 ± 0.7) %		211
$\Xi^0 \pi^-$		(23.6 ± 0.7) %		294
$\Xi^- \pi^0$		(8.6 ± 0.4) %		289
$\Xi^- \pi^+ \pi^-$		$(3.7^{+0.7}_{-0.6}) \times 10^{-4}$		189
$\Xi(1530)^0 \pi^-$		$< 7 \times 10^{-5}$	90%	17
$\Xi^0 e^- \overline{\nu}_e$		$(5.6 \pm 2.8) \times 10^{-3}$		319
$\Xi^- \gamma$		$< 4.6 \times 10^{-4}$	90%	314
$\Delta S = 2$ forbidden ($S2$) modes				
$\Lambda \pi^-$	$S2$	$< 2.9 \times 10^{-6}$	90%	449

$\Omega(2012)^-$

$I(J^P) = 0(?^-)$

Mass $m = 2012.4 \pm 0.9$ MeV
Full width $\Gamma = 6.4^{+3.0}_{-2.6}$ MeV

$\Omega(2012)^-$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\Xi^0 K^-$	**DEFINED AS 1**		403
$\Xi^- K^0$	0.83 ± 0.21		392
$\Xi^0 \pi^0 K^-$	<0.30	90%	245
$\Xi^0 \pi^- \overline{K}^0$	<0.21	90%	230
$\Xi^- \pi^+ K^-$	<0.08	90%	224

$\Omega(2250)^-$

$I(J^P) = 0(?^?)$

Mass $m = 2252 \pm 9$ MeV
Full width $\Gamma = 55 \pm 18$ MeV

CHARMED BARYONS
($C = +1$)

$\Lambda_c^+ = udc$, $\Sigma_c^{++} = uuc$, $\Sigma_c^+ = udc$, $\Sigma_c^0 = ddc$,
$\Xi_c^+ = usc$, $\Xi_c^0 = dsc$, $\Omega_c^0 = ssc$

Λ_c^+

$I(J^P) = 0(\frac{1}{2}^+)$

Mass $m = 2286.46 \pm 0.14$ MeV
Mean life $\tau = (202.4 \pm 3.1) \times 10^{-15}$ s (S = 1.7)
$c\tau = 60.7$ μm

Decay asymmetry parameters

$\Lambda\pi^+$ $\alpha = -0.84 \pm 0.09$
$\Sigma^+\pi^0$ $\alpha = -0.55 \pm 0.11$
α FOR $\Lambda_c^+ \to \Sigma^0\pi^+ = -0.73 \pm 0.18$
$\Lambda\ell^+\nu_\ell$ $\alpha = -0.86 \pm 0.04$
α FOR $\Lambda_c^+ \to pK_S^0 = 0.2 \pm 0.5$
$(\alpha + \overline{\alpha})/(\alpha - \overline{\alpha})$ in $\Lambda_c^+ \to \Lambda\pi^+$, $\overline{\Lambda}_c^- \to \overline{\Lambda}\pi^- = -0.07 \pm 0.31$
$(\alpha + \overline{\alpha})/(\alpha - \overline{\alpha})$ in $\Lambda_c^+ \to \Lambda e^+\nu_e$, $\overline{\Lambda}_c^- \to \overline{\Lambda} e^-\overline{\nu}_e = 0.00 \pm 0.04$
$A_{CP}(\Lambda X)$ in $\Lambda_c \to \Lambda X$, $\overline{\Lambda}_c \to \overline{\Lambda} X = (2 \pm 7)\%$
$\Delta A_{CP} = A_{CP}(\Lambda_c^+ \to pK^+K^-) - A_{CP}(\Lambda_c^+ \to p\pi^+\pi^-) =$
$(0.3 \pm 1.1)\%$

Branching fractions marked with a footnote, e.g. [a], have been corrected for decay modes not observed in the experiments. For example, the submode fraction $\Lambda_c^+ \to p\overline{K}^*(892)^0$ seen in $\Lambda_c^+ \to pK^-\pi^+$ has been multiplied up to include $\overline{K}^*(892)^0 \to \overline{K}^0\pi^0$ decays.

Λ_c^+ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Hadronic modes with a p or n: $S = -1$ final states				
pK_S^0		(1.59± 0.08) %	S=1.1	873
$pK^-\pi^+$		(6.28± 0.32) %	S=1.4	823
$p\overline{K}^*(892)^0$	[r]	(1.96± 0.27) %		685
$\Delta(1232)^{++}K^-$		(1.08± 0.25) %		710
$\Lambda(1520)\pi^+$	[r]	(2.2 ± 0.5) %		628
$pK^-\pi^+$ nonresonant		(3.5 ± 0.4) %		823
$pK_S^0\pi^0$		(1.97± 0.13) %	S=1.1	823
$nK_S^0\pi^+$		(1.82± 0.25) %		821
$p\overline{K}^0\eta$		(1.6 ± 0.4) %		568
$pK_S^0\pi^+\pi^-$		(1.60± 0.12) %	S=1.1	754
$pK^-\pi^+\pi^0$		(4.46± 0.30) %	S=1.5	759
$pK^*(892)^-\pi^+$	[r]	(1.4 ± 0.5) %		580
$p(K^-\pi^+)_{\text{nonresonant}}\pi^0$		(4.6 ± 0.8) %		759
$pK^-2\pi^+\pi^-$		(1.4 ± 0.9) $\times 10^{-3}$		671
$pK^-\pi^+2\pi^0$		(1.0 ± 0.5) %		678

Hadronic modes with a p: $S = 0$ final states

$p\pi^0$		$< 2.7 \times 10^{-4}$	CL=90%	945
$p\eta$		$(1.24 \pm 0.30) \times 10^{-3}$		856
$p\omega(782)^0$		$(9 \pm 4) \times 10^{-4}$		751
$p\pi^+\pi^-$		$(4.61 \pm 0.28) \times 10^{-3}$		927
$p f_0(980)$	[r]	$(3.5 \pm 2.3) \times 10^{-3}$		614
$p 2\pi^+ 2\pi^-$		$(2.3 \pm 1.4) \times 10^{-3}$		852
$p K^+ K^-$		$(1.06 \pm 0.06) \times 10^{-3}$		616
$p\phi$	[r]	$(1.06 \pm 0.14) \times 10^{-3}$		590
$p K^+ K^-$ non-ϕ		$(5.3 \pm 1.2) \times 10^{-4}$		616
$p\phi\pi^0$		$(10 \pm 4) \times 10^{-5}$		460
$p K^+ K^- \pi^0$ nonresonant		$< 6.3 \times 10^{-5}$	CL=90%	494

Hadronic modes with a hyperon: $S = -1$ final states

$\Lambda\pi^+$		(1.30 ± 0.07) %	S=1.1	864
$\Lambda\pi^+\pi^0$		(7.1 ± 0.4) %	S=1.1	844
$\Lambda\rho^+$		< 6 %	CL=95%	636
$\Lambda\pi^- 2\pi^+$		(3.64 ± 0.29) %	S=1.4	807
$\Sigma(1385)^+\pi^+\pi^-$, $\Sigma^{*+} \to \Lambda\pi^+$		(1.0 ± 0.5) %		688
$\Sigma(1385)^- 2\pi^+$, $\Sigma^{*-} \to \Lambda\pi^-$		$(7.6 \pm 1.4) \times 10^{-3}$		688
$\Lambda\pi^+\rho^0$		(1.5 ± 0.6) %		524
$\Sigma(1385)^+\rho^0$, $\Sigma^{*+} \to \Lambda\pi^+$		$(5 \pm 4) \times 10^{-3}$		363
$\Lambda\pi^- 2\pi^+$ nonresonant		< 1.1 %	CL=90%	807
$\Lambda\pi^-\pi^0 2\pi^+$ total		(2.3 ± 0.8) %		757
$\Lambda\pi^+\eta$	[r]	(1.84 ± 0.26) %		691
$\Sigma(1385)^+\eta$	[r]	$(9.1 \pm 2.0) \times 10^{-3}$		570
$\Lambda\pi^+\omega$	[r]	(1.5 ± 0.5) %		517
$\Lambda\pi^-\pi^0 2\pi^+$, no η or ω		$< 8 \times 10^{-3}$	CL=90%	757
$\Lambda K^+\overline{K}^0$		$(5.7 \pm 1.1) \times 10^{-3}$	S=1.9	443
$\Xi(1690)^0 K^+$, $\Xi^{*0} \to \Lambda\overline{K}^0$		$(1.6 \pm 0.5) \times 10^{-3}$		286
$\Sigma^0\pi^+$		(1.29 ± 0.07) %	S=1.1	825
$\Sigma^+\pi^0$		(1.25 ± 0.10) %		827
$\Sigma^+\eta$		$(4.4 \pm 2.0) \times 10^{-3}$		713
$\Sigma^+\eta'$		(1.5 ± 0.6) %		391
$\Sigma^+\pi^+\pi^-$		(4.50 ± 0.25) %	S=1.3	804
$\Sigma^+\rho^0$		< 1.7 %	CL=95%	575
$\Sigma^- 2\pi^+$		(1.87 ± 0.18) %		799
$\Sigma^0\pi^+\pi^0$		(3.5 ± 0.4) %		803
$\Sigma^+\pi^0\pi^0$		(1.55 ± 0.15) %		806
$\Sigma^0\pi^- 2\pi^+$		(1.11 ± 0.30) %		763
$\Sigma^+\pi^+\pi^-\pi^0$		—		767
$\Sigma^+\omega$	[r]	(1.70 ± 0.21) %		569
$\Sigma^-\pi^0 2\pi^+$		(2.1 ± 0.4) %		762
$\Sigma^+ K^+ K^-$		$(3.5 \pm 0.4) \times 10^{-3}$	S=1.1	349
$\Sigma^+\phi$	[r]	$(3.9 \pm 0.6) \times 10^{-3}$	S=1.1	295
$\Xi(1690)^0 K^+$, $\Xi^{*0} \to \Sigma^+ K^-$		$(1.02 \pm 0.25) \times 10^{-3}$		286
$\Sigma^+ K^+ K^-$ nonresonant		$< 8 \times 10^{-4}$	CL=90%	349
$\Xi^0 K^+$		$(5.5 \pm 0.7) \times 10^{-3}$		653
$\Xi^- K^+\pi^+$		$(6.2 \pm 0.6) \times 10^{-3}$	S=1.1	565
$\Xi(1530)^0 K^+$		$(4.3 \pm 0.9) \times 10^{-3}$	S=1.1	473

Hadronic modes with a hyperon: $S = 0$ final states

ΛK^+		$(6.1 \pm 1.2) \times 10^{-4}$		781
$\Lambda K^+\pi^+\pi^-$		$< 5 \times 10^{-4}$	CL=90%	637
$\Sigma^0 K^+$		$(5.2 \pm 0.8) \times 10^{-4}$		735

$\Sigma^0 K^+ \pi^+ \pi^-$		$< 2.6 \times 10^{-4}$	CL=90%	574
$\Sigma^+ K^+ \pi^-$		$(2.1 \pm 0.6) \times 10^{-3}$		670
$\Sigma^+ K^*(892)^0$	[r]	$(3.5 \pm 1.0) \times 10^{-3}$		470
$\Sigma^- K^+ \pi^+$		$< 1.2 \times 10^{-3}$	CL=90%	664

Doubly Cabibbo-suppressed modes

$p K^+ \pi^-$	$(1.11 \pm 0.18) \times 10^{-4}$		823

Semileptonic modes

$\Lambda e^+ \nu_e$	(3.6 ± 0.4) %	871
$\Lambda \mu^+ \nu_\mu$	(3.5 ± 0.5) %	867

Inclusive modes

e^+ anything	(3.95 ± 0.35) %	–
p anything	(50 ± 16) %	–
n anything	(50 ± 16) %	–
Λ anything	$(38.2 {}^{+2.9}_{-2.4})$ %	–
3prongs	(24 ± 8) %	–

$\Delta C = 1$ weak neutral current (*C1*) modes, or Lepton Family number (*LF*), or Lepton number (*L*), or Baryon number (*B*) violating modes

$p e^+ e^-$	*C1*	$< 5.5 \times 10^{-6}$	CL=90%	951
$p \mu^+ \mu^-$ non-resonant	*C1*	$< 7.7 \times 10^{-8}$	CL=90%	937
$p e^+ \mu^-$	*LF*	$< 9.9 \times 10^{-6}$	CL=90%	947
$p e^- \mu^+$	*LF*	$< 1.9 \times 10^{-5}$	CL=90%	947
$\overline{p} 2e^+$	*L,B*	$< 2.7 \times 10^{-6}$	CL=90%	951
$\overline{p} 2\mu^+$	*L,B*	$< 9.4 \times 10^{-6}$	CL=90%	937
$\overline{p} e^+ \mu^+$	*L,B*	$< 1.6 \times 10^{-5}$	CL=90%	947
$\Sigma^- \mu^+ \mu^+$	*L*	$< 7.0 \times 10^{-4}$	CL=90%	812

See Particle Listings for 1 decay modes that have been seen / not seen.

$\Lambda_c(2595)^+$

$I(J^P) = 0(\frac{1}{2}^-)$

The spin-parity follows from the fact that $\Sigma_c(2455)\pi$ decays, with little available phase space, are dominant. This assumes that $J^P = 1/2^+$ for the $\Sigma_c(2455)$.

Mass $m = 2592.25 \pm 0.28$ MeV
$m - m_{\Lambda_c^+} = 305.79 \pm 0.24$ MeV
Full width $\Gamma = 2.6 \pm 0.6$ MeV

$\Lambda_c^+ \pi\pi$ and its submode $\Sigma_c(2455)\pi$ — the latter just barely — are the only strong decays allowed to an excited Λ_c^+ having this mass; and the submode seems to dominate.

$\Lambda_c(2595)^+$ DECAY MODES		Fraction (Γ_i/Γ)	p (MeV/c)
$\Lambda_c^+ \pi^+ \pi^-$	[s]	—	117
$\Sigma_c(2455)^{++} \pi^-$		24 ± 7 %	†
$\Sigma_c(2455)^0 \pi^+$		24 ± 7 %	†
$\Lambda_c^+ \pi^+ \pi^-$ 3-body		18 ± 10 %	117

See Particle Listings for 2 decay modes that have been seen / not seen.

$\Lambda_c(2625)^+$

$I(J^P) = 0(\frac{3}{2}^-)$

J^P has not been measured; $\frac{3}{2}^-$ is the quark-model prediction.

Mass $m = 2628.11 \pm 0.19$ MeV (S = 1.1)
$m - m_{\Lambda_c^+} = 341.65 \pm 0.13$ MeV (S = 1.1)
Full width $\Gamma < 0.97$ MeV, CL = 90%

$\Lambda_c^+ \pi\pi$ and its submode $\Sigma(2455)\pi$ are the only strong decays allowed to an excited Λ_c^+ having this mass.

$\Lambda_c(2625)^+$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\Lambda_c^+ \pi^+ \pi^-$	$\approx$ 67%		184
$\Sigma_c(2455)^{++} \pi^-$	<5	90%	102
$\Sigma_c(2455)^0 \pi^+$	<5	90%	102
$\Lambda_c^+ \pi^+ \pi^-$ 3-body	large		184

See Particle Listings for 2 decay modes that have been seen / not seen.

$\Lambda_c(2860)^+$

$I(J^P) = 0(\frac{3}{2}^+)$

Mass $m = 2856.1^{+2.3}_{-6.0}$ MeV
Full width $\Gamma = 68^{+12}_{-22}$ MeV

$\Lambda_c(2880)^+$

$I(J^P) = 0(\frac{5}{2}^+)$

Mass $m = 2881.63 \pm 0.24$ MeV
$m - m_{\Lambda_c^+} = 595.17 \pm 0.28$ MeV
Full width $\Gamma = 5.6^{+0.8}_{-0.6}$ MeV

$\Lambda_c(2940)^+$

$I(J^P) = 0(\frac{3}{2}^-)$

$J^P = 3/2^-$ is favored, but is not certain

Mass $m = 2939.6^{+1.3}_{-1.5}$ MeV
Full width $\Gamma = 20^{+6}_{-5}$ MeV

$\Sigma_c(2455)$

$I(J^P) = 1(\frac{1}{2}^+)$

$\Sigma_c(2455)^{++}$ mass $m = 2453.97 \pm 0.14$ MeV
$\Sigma_c(2455)^{+}$ mass $m = 2452.9 \pm 0.4$ MeV
$\Sigma_c(2455)^{0}$ mass $m = 2453.75 \pm 0.14$ MeV
$m_{\Sigma_c^{++}} - m_{\Lambda_c^+} = 167.510 \pm 0.017$ MeV
$m_{\Sigma_c^{+}} - m_{\Lambda_c^+} = 166.4 \pm 0.4$ MeV
$m_{\Sigma_c^{0}} - m_{\Lambda_c^+} = 167.290 \pm 0.017$ MeV
$m_{\Sigma_c^{++}} - m_{\Sigma_c^0} = 0.220 \pm 0.013$ MeV
$m_{\Sigma_c^{+}} - m_{\Sigma_c^0} = -0.9 \pm 0.4$ MeV

$\Sigma_c(2455)^{++}$ full width $\Gamma = 1.89^{+0.09}_{-0.18}$ MeV (S = 1.1)
$\Sigma_c(2455)^{+}$ full width $\Gamma < 4.6$ MeV, CL = 90%
$\Sigma_c(2455)^{0}$ full width $\Gamma = 1.83^{+0.11}_{-0.19}$ MeV (S = 1.2)

$\Lambda_c^+ \pi$ is the only strong decay allowed to a Σ_c having this mass.

Σ_c(2455) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Lambda_c^+ \pi$	≈ 100 %	94

Σ_c(2520)

$I(J^P) = 1(\frac{3}{2}^+)$

J^P has not been measured; $\frac{3}{2}^+$ is the quark-model prediction.

$\Sigma_c(2520)^{++}$ mass $m = 2518.41^{+0.21}_{-0.19}$ MeV (S = 1.1)
$\Sigma_c(2520)^{+}$ mass $m = 2517.5 \pm 2.3$ MeV
$\Sigma_c(2520)^{0}$ mass $m = 2518.48 \pm 0.20$ MeV (S = 1.1)
$m_{\Sigma_c(2520)^{++}} - m_{\Lambda_c^+} = 231.95^{+0.17}_{-0.12}$ MeV (S = 1.3)
$m_{\Sigma_c(2520)^{+}} - m_{\Lambda_c^+} = 231.0 \pm 2.3$ MeV
$m_{\Sigma_c(2520)^{0}} - m_{\Lambda_c^+} = 232.02^{+0.15}_{-0.14}$ MeV (S = 1.3)
$m_{\Sigma_c(2520)^{++}} - m_{\Sigma_c(2520)^{0}} = 0.01 \pm 0.15$ MeV
$\Sigma_c(2520)^{++}$ full width $\Gamma = 14.78^{+0.30}_{-0.40}$ MeV
$\Sigma_c(2520)^{+}$ full width $\Gamma < 17$ MeV, CL = 90%
$\Sigma_c(2520)^{0}$ full width $\Gamma = 15.3^{+0.4}_{-0.5}$ MeV

$\Lambda_c^+ \pi$ is the only strong decay allowed to a Σ_c having this mass.

Σ_c(2520) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Lambda_c^+ \pi$	≈ 100 %	179

Σ_c(2800)

$I(J^P) = 1(?^?)$

$\Sigma_c(2800)^{++}$ mass $m = 2801^{+4}_{-6}$ MeV
$\Sigma_c(2800)^{+}$ mass $m = 2792^{+14}_{-5}$ MeV
$\Sigma_c(2800)^{0}$ mass $m = 2806^{+5}_{-7}$ MeV (S = 1.3)
$m_{\Sigma_c(2800)^{++}} - m_{\Lambda_c^+} = 514^{+4}_{-6}$ MeV
$m_{\Sigma_c(2800)^{+}} - m_{\Lambda_c^+} = 505^{+14}_{-5}$ MeV
$m_{\Sigma_c(2800)^{0}} - m_{\Lambda_c^+} = 519^{+5}_{-7}$ MeV (S = 1.3)
$\Sigma_c(2800)^{++}$ full width $\Gamma = 75^{+22}_{-17}$ MeV
$\Sigma_c(2800)^{+}$ full width $\Gamma = 62^{+60}_{-40}$ MeV
$\Sigma_c(2800)^{0}$ full width $\Gamma = 72^{+22}_{-15}$ MeV

Ξ_c^+

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

J^P has not been measured; $\frac{1}{2}^+$ is the quark-model prediction.

Mass $m = 2467.94^{+0.17}_{-0.20}$ MeV
Mean life $\tau = (456 \pm 5) \times 10^{-15}$ s
$c\tau = 136.6\ \mu$m

Branching fractions marked with a footnote, e.g. [a], have been corrected for decay modes not observed in the experiments. For example, the submode fraction $\Xi_c^+ \to \Sigma^+ \overline{K}^*(892)^0$ seen in $\Xi_c^+ \to \Sigma^+ K^- \pi^+$ has been multiplied up to include $\overline{K}^*(892)^0 \to \overline{K}^0 \pi^0$ decays.

Ξ_c^+ DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
No absolute branching fractions have been measured. The following are branching *ratios* relative to $\Xi^- 2\pi^+$.				
Cabibbo-favored ($S = -2$) decays — relative to $\Xi^- 2\pi^+$				
$p 2K_S^0$		0.087 ±0.021		767
$\Lambda \overline{K}^0 \pi^+$		—		852
$\Sigma(1385)^+ \overline{K}^0$	[r]	1.0 ±0.5		746
$\Lambda K^- 2\pi^+$		0.323 ±0.033		787
$\Lambda \overline{K}^*(892)^0 \pi^+$	[r]	< 0.16	90%	608
$\Sigma(1385)^+ K^- \pi^+$	[r]	< 0.23	90%	678
$\Sigma^+ K^- \pi^+$		0.94 ±0.10		811
$\Sigma^+ \overline{K}^*(892)^0$	[r]	0.81 ±0.15		658
$\Sigma^0 K^- 2\pi^+$		0.27 ±0.12		735
$\Xi^0 \pi^+$		0.55 ±0.16		877
$\Xi^- 2\pi^+$		**DEFINED AS 1**		851
$\Xi(1530)^0 \pi^+$	[r]	< 0.10	90%	750
$\Xi^0 \pi^+ \pi^0$		2.3 ±0.7		856
$\Xi^0 \pi^- 2\pi^+$		1.7 ±0.5		818
$\Xi^0 e^+ \nu_e$		2.3 $^{+0.7}_{-0.8}$		884
$\Omega^- K^+ \pi^+$		0.07 ±0.04		399
Cabibbo-suppressed decays — relative to $\Xi^- 2\pi^+$				
$p K^- \pi^+$		0.0045±0.0022		944
$p \overline{K}^*(892)^0$	[r]	0.0024±0.0013		828
$\Sigma^+ \pi^+ \pi^-$		0.48 ±0.20		922
$\Sigma^- 2\pi^+$		0.18 ±0.09		918
$\Sigma^+ K^+ K^-$		0.15 ±0.06		580
$\Sigma^+ \phi$	[r]	< 0.11	90%	549
$\Xi(1690)^0 K^+$, $\Xi^0 \to \Sigma^+ K^-$		< 0.05	90%	501
$p \phi(1020)$		$(9 \pm 4) \times 10^{-5}$		751

See Particle Listings for 2 decay modes that have been seen / not seen.

Ξ_c^0

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

J^P has not been measured; $\frac{1}{2}^+$ is the quark-model prediction.

Mass $m = 2470.90^{+0.22}_{-0.29}$ MeV
$m_{\Xi_c^0} - m_{\Xi_c^+} = 2.96 \pm 0.22$ MeV
Mean life $\tau = (153 \pm 6) \times 10^{-15}$ s (S = 2.4)
$c\tau = 45.8$ μm

Decay asymmetry parameters

$\Xi^- \pi^+$ $\alpha = -0.6 \pm 0.4$

Ξ_c^0 DECAY MODES	Fraction (Γ_i/Γ)	Scale factor	p (MeV/c)
Cabibbo-favored (S = −2) decays			
$pK^- K^- \pi^+$	$(4.8 \pm 1.2) \times 10^{-3}$	1.1	676
$pK^- \overline{K}^*(892)^0$, $\overline{K}^{*0} \to K^- \pi^+$	$(2.0 \pm 0.6) \times 10^{-3}$		413
$pK^- K^- \pi^+$ (no $\overline{K}^{*0}$)	$(3.0 \pm 0.9) \times 10^{-3}$		676
ΛK_S^0	$(3.0 \pm 0.8) \times 10^{-3}$		906
$\Lambda K^- \pi^+$	(1.45 ± 0.33) %	1.1	856
$\Xi^- \pi^+$	(1.43 ± 0.32) %	1.1	875
$\Xi^- \pi^+ \pi^+ \pi^-$	(4.8 ± 2.3) %		816
$\Omega^- K^+$	$(4.2 \pm 1.0) \times 10^{-3}$		522
$\Xi^- e^+ \nu_e$	(1.8 ± 1.2) %		882
Cabibbo-suppressed decays			
$\Xi^- K^+$	$(3.9 \pm 1.2) \times 10^{-4}$		790
$\Lambda K^+ K^-$ (no ϕ)	$(4.1 \pm 1.4) \times 10^{-4}$		648
$\Lambda \phi$	$(4.9 \pm 1.5) \times 10^{-4}$		621

See Particle Listings for 2 decay modes that have been seen / not seen.

$\Xi_c^{\prime +}$

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

J^P has not been measured; $\frac{1}{2}^+$ is the quark-model prediction.

Mass $m = 2578.4 \pm 0.5$ MeV
$m_{\Xi_c^{\prime +}} - m_{\Xi_c^+} = 110.5 \pm 0.4$ MeV
$m_{\Xi_c^{\prime +}} - m_{\Xi_c^{\prime 0}} = -0.8 \pm 0.6$ MeV

$\Xi_c^{\prime 0}$

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

J^P has not been measured; $\frac{1}{2}^+$ is the quark-model prediction.

Mass $m = 2579.2 \pm 0.5$ MeV
$m_{\Xi_c^{\prime 0}} - m_{\Xi_c^0} = 108.3 \pm 0.4$ MeV

$\Xi_c(2645)$

$I(J^P) = \frac{1}{2}(\frac{3}{2}^+)$

J^P has not been measured; $\frac{3}{2}^+$ is the quark-model prediction.

$\Xi_c(2645)^+$ mass $m = 2645.56^{+0.24}_{-0.30}$ MeV
$\Xi_c(2645)^0$ mass $m = 2646.38^{+0.20}_{-0.23}$ MeV (S = 1.1)
$m_{\Xi_c(2645)^+} - m_{\Xi_c^0} = 174.66 \pm 0.09$ MeV
$m_{\Xi_c(2645)^0} - m_{\Xi_c^+} = 178.44 \pm 0.10$ MeV
$m_{\Xi_c(2645)^+} - m_{\Xi_c(2645)^0} = -0.82 \pm 0.26$ MeV
$\Xi_c(2645)^+$ full width $\Gamma = 2.14 \pm 0.19$ MeV (S = 1.1)
$\Xi_c(2645)^0$ full width $\Gamma = 2.35 \pm 0.22$ MeV

$\Xi_c(2790)$

$I(J^P) = \frac{1}{2}(\frac{1}{2}^-)$

J^P has not been measured; $\frac{1}{2}^-$ is the quark-model prediction.

$\Xi_c(2790)^+$ mass $= 2792.4 \pm 0.5$ MeV
$\Xi_c(2790)^0$ mass $= 2794.1 \pm 0.5$ MeV
$m_{\Xi_c(2790)^+} - m_{\Xi_c'^0} = 213.20 \pm 0.22$ MeV
$m_{\Xi_c(2790)^0} - m_{\Xi_c'^+} = 215.70 \pm 0.22$ MeV
$m_{\Xi_c(2790)^+} - m_{\Xi_c(2790)^0} = -1.7 \pm 0.7$ MeV
$\Xi_c(2790)^+$ width $= 8.9 \pm 1.0$ MeV
$\Xi_c(2790)^0$ width $= 10.0 \pm 1.1$ MeV

$\Xi_c(2815)$

$I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$

J^P has not been measured; $\frac{3}{2}^-$ is the quark-model prediction.

$\Xi_c(2815)^+$ mass $m = 2816.74^{+0.20}_{-0.23}$ MeV
$\Xi_c(2815)^0$ mass $m = 2820.25^{+0.25}_{-0.31}$ MeV
$m_{\Xi_c(2815)^+} - m_{\Xi_c^+} = 348.80 \pm 0.10$ MeV
$m_{\Xi_c(2815)^0} - m_{\Xi_c^0} = 349.35 \pm 0.11$ MeV
$m_{\Xi_c(2815)^+} - m_{\Xi_c(2815)^0} = -3.51 \pm 0.26$ MeV
$\Xi_c(2815)^+$ full width $\Gamma = 2.43 \pm 0.26$ MeV
$\Xi_c(2815)^0$ full width $\Gamma = 2.54 \pm 0.25$ MeV

$\Xi_c(2970)$

$I(J^P) = \frac{1}{2}(?^?)$

was $\Xi_c(2980)$

$\Xi_c(2970)^+$ $m = 2966.34^{+0.17}_{-1.00}$ MeV
$\Xi_c(2970)^0$ $m = 2970.9^{+0.4}_{-0.6}$ MeV
\quad $m_{\Xi_c(2970)^+} - m_{\Xi_c^+} = 498.40^{+0.27}_{-0.90}$ MeV
\quad $m_{\Xi_c(2970)^0} - m_{\Xi_c^0} = 500.0^{+0.4}_{-0.6}$ MeV
$m_{\Xi_c(2970)^+} - m_{\Xi_c(2970)^0} = -4.6^{+0.4}_{-0.6}$ MeV
$\Xi_c(2970)^+$ width $\Gamma = 20.9^{+2.4}_{-3.5}$ MeV (S = 1.2)
$\Xi_c(2970)^0$ width $\Gamma = 28.1^{+3.4}_{-4.0}$ MeV (S = 1.5)

$\Xi_c(3055)$

$I(J^P) = ?(?^?)$

Mass $m = 3055.9 \pm 0.4$ MeV
Full width $\Gamma = 7.8 \pm 1.9$ MeV

$\Xi_c(3080)$

$I(J^P) = \frac{1}{2}(?^?)$

$\Xi_c(3080)^+$ $m = 3077.2 \pm 0.4$ MeV
$\Xi_c(3080)^0$ $m = 3079.9 \pm 1.4$ MeV (S = 1.3)
$\Xi_c(3080)^+$ width $\Gamma = 3.6 \pm 1.1$ MeV (S = 1.5)
$\Xi_c(3080)^0$ width $\Gamma = 5.6 \pm 2.2$ MeV

Ω_c^0

$I(J^P) = 0(\frac{1}{2}^+)$

J^P has not been measured; $\frac{1}{2}^+$ is the quark-model prediction.

Mass $m = 2695.2 \pm 1.7$ MeV (S = 1.3)
Mean life $\tau = (268 \pm 26) \times 10^{-15}$ s
$c\tau = 80\ \mu$m

Ω_c^0 DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)

No absolute branching fractions have been measured.
The following are branching *ratios* relative to $\Omega^-\pi^+$.

Cabibbo-favored ($S = -3$) decays — relative to $\Omega^-\pi^+$

$\Omega^-\pi^+$	**DEFINED AS 1**		821
$\Omega^-\pi^+\pi^0$	1.80 ± 0.33		797
$\Omega^-\rho^+$	>1.3	90%	532
$\Omega^-\pi^-2\pi^+$	0.31 ± 0.05		753
$\Omega^-e^+\nu_e$	2.4 ± 1.2		829
$\Xi^0\overline{K}^0$	1.64 ± 0.29		950
$\Xi^0K^-\pi^+$	1.20 ± 0.18		901
$\Xi^0\overline{K}^{*0}$, $\overline{K}^{*0} \to K^-\pi^+$	0.68 ± 0.16		764
$\Xi^-\overline{K}^0\pi^+$	2.12 ± 0.28		895
$\Xi^-K^-2\pi^+$	0.63 ± 0.09		830
$\Xi(1530)^0K^-\pi^+$, $\Xi^{*0} \to \Xi^-\pi^+$	0.21 ± 0.06		757
$\Xi^-\overline{K}^{*0}\pi^+$	0.34 ± 0.11		653
$\Sigma^+K^-K^-\pi^+$	<0.32	90%	689
$\Lambda\overline{K}^0\overline{K}^0$	1.72 ± 0.35		837

$\Omega_c(2770)^0$

$I(J^P) = 0(\frac{3}{2}^+)$

J^P has not been measured; $\frac{3}{2}^+$ is the quark-model prediction.

Mass $m = 2765.9 \pm 2.0$ MeV (S = 1.2)
$m_{\Omega_c(2770)^0} - m_{\Omega_c^0} = 70.7^{+0.8}_{-0.9}$ MeV

The $\Omega_c(2770)^0$–Ω_c^0 mass difference is too small for any strong decay to occur.

$\Omega_c(2770)^0$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Omega_c^0\gamma$	presumably 100%	70

$\Omega_c(3000)^0$

$I(J^P) = ?(?^?)$

Mass $m = 3000.41 \pm 0.22$ MeV
Full width $\Gamma = 4.5 \pm 0.7$ MeV

$\Omega_c(3050)^0$

$I(J^P) = ?(?^?)$

Mass $m = 3050.20 \pm 0.13$ MeV
Full width $\Gamma < 1.2$ MeV, CL = 95%

$\Omega_c(3065)^0$

$I(J^P) = ?(?^?)$

Mass $m = 3065.46 \pm 0.28$ MeV
Full width $\Gamma = 3.5 \pm 0.4$ MeV

$\Omega_c(3090)^0$

$I(J^P) = ?(?^?)$

Mass $m = 3090.0 \pm 0.5$ MeV
Full width $\Gamma = 8.7 \pm 1.3$ MeV

$\Omega_c(3120)^0$

$I(J^P) = ?(?^?)$

Mass $m = 3119.1 \pm 1.0$ MeV
Full width $\Gamma < 2.6$ MeV, CL = 95%

DOUBLY CHARMED BARYONS ($C = +2$)

$\Xi_{cc}^{++} = u\,c\,c$, $\Xi_{cc}^{+} = d\,c\,c$, $\Omega_{cc}^{+} = s\,c\,c$

Ξ_{cc}^{++}

$I(J^P) = ?(?^?)$

Mass $m = 3621.2 \pm 0.7$ MeV
Mean life $\tau = (256 \pm 27) \times 10^{-15}$ s

BOTTOM BARYONS ($B = -1$)

$\Lambda_b^0 = u\,d\,b$, $\Xi_b^0 = u\,s\,b$, $\Xi_b^- = d\,s\,b$, $\Omega_b^- = s\,s\,b$

Λ_b^0

$I(J^P) = 0(\frac{1}{2}^+)$

$I(J^P)$ not yet measured; $0(\frac{1}{2}^+)$ is the quark model prediction.

Mass $m = 5619.60 \pm 0.17$ MeV
$m_{\Lambda_b^0} - m_{B^0} = 339.2 \pm 1.4$ MeV
$m_{\Lambda_b^0} - m_{B^+} = 339.72 \pm 0.28$ MeV
Mean life $\tau = (1.471 \pm 0.009) \times 10^{-12}$ s
$c\tau = 441.0$ μm

$A_{CP}(\Lambda_b \to p\pi^-) = -0.025 \pm 0.029$ (S = 1.2)
$A_{CP}(\Lambda_b \to pK^-) = -0.025 \pm 0.022$
$\Delta A_{CP}(pK^- / \pi^-) = 0.014 \pm 0.024$
$A_{CP}(\Lambda_b \to p\overline{K}^0\pi^-) = 0.22 \pm 0.13$
$\Delta A_{CP}(J/\psi p\pi^- / K^-) = (5.7 \pm 2.7) \times 10^{-2}$
$A_{CP}(\Lambda_b \to \Lambda K^+\pi^-) = -0.53 \pm 0.25$
$A_{CP}(\Lambda_b \to \Lambda K^+K^-) = -0.28 \pm 0.12$
$\Delta A_{CP}(\Lambda_b^0 \to pK^-\mu^+\mu^-) = (-4 \pm 5) \times 10^{-2}$
$\Delta A_{CP}(\Lambda_b^0 \to p\pi^-\pi^+\pi^-) = (1.1 \pm 2.6) \times 10^{-2}$
$\Delta A_{CP}(\Lambda_b^0 \to (p\pi^-\pi^+\pi^-)_{LBM}) = (4 \pm 4) \times 10^{-2}$
$\Delta A_{CP}(\Lambda_b^0 \to pa_1(1260)^-) = (-1 \pm 4) \times 10^{-2}$
$\Delta A_{CP}(\Lambda_b^0 \to N(1520)^0\rho(770)^0) = (2 \pm 5) \times 10^{-2}$
$\Delta A_{CP}(\Lambda_b^0 \to \Delta(1232)^{++}\pi^-\pi^-) = (0.1 \pm 3.3) \times 10^{-2}$
$\Delta A_{CP}(\Lambda_b^0 \to pK^-\pi^+\pi^-) = (3.2 \pm 1.3) \times 10^{-2}$
$\Delta A_{CP}(\Lambda_b^0 \to (pK^-\pi^+\pi^-)_{LBM}) = (3.5 \pm 1.6) \times 10^{-2}$
$\Delta A_{CP}(\Lambda_b^0 \to N(1520)^0K^*(892)^0) = (5.5 \pm 2.5) \times 10^{-2}$
$\Delta A_{CP}(\Lambda_b^0 \to \Lambda(1520)\rho(770)^0) = (1 \pm 6) \times 10^{-2}$
$\Delta A_{CP}(\Lambda_b^0 \to \Delta(1232)^{++}K^-\pi^-) = (4.4 \pm 2.7) \times 10^{-2}$
$\Delta A_{CP}(\Lambda_b^0 \to pK_1(1410)^-) = (5 \pm 4) \times 10^{-2}$
$\Delta A_{CP}(\Lambda_b^0 \to pK^-K^+\pi^-) = (-7 \pm 5) \times 10^{-2}$
$\Delta A_{CP}(\Lambda_b^0 \to pK^-K^+K^-) = (0.2 \pm 1.9) \times 10^{-2}$
$\Delta A_{CP}(\Lambda_b^0 \to \Lambda(1520)\phi(1020)) = (4 \pm 6) \times 10^{-2}$
$\Delta A_{CP}(\Lambda_b^0 \to (pK^-)_{highmass}\,\phi(1020)) = (-0.7 \pm 3.4) \times 10^{-2}$
$\Delta A_{CP}(\Lambda_b^0 \to (pK^-K^+K^-)_{LBM}) = (2.7 \pm 2.4) \times 10^{-2}$
$A^{\ell}_{FB}(\mu\mu)$ in $\Lambda_b \to \Lambda\mu^+\mu^- = -0.39 \pm 0.04$
$\Delta(A^{\ell}_{FB}(\mu\mu))$ in $\Lambda_b \to \Lambda\mu^+\mu^- = -0.05 \pm 0.09$
$A^{h}_{FB}(p\pi)$ in $\Lambda_b \to \Lambda(p\pi)\mu^+\mu^- = -0.30 \pm 0.05$
$A^{\ell h}_{FB}$ in $\Lambda_b \to \Lambda\mu^+\mu^- = 0.25 \pm 0.04$

The branching fractions B(b-baryon $\to$ $\Lambda\ell^-\overline{\nu}_\ell$anything) and B($\Lambda_b^0 \to \Lambda_c^+\ell^-\overline{\nu}_\ell$anything) are not pure measurements because the underlying measured products of these with B($b \to$ b-baryon) were used to determine B($b \to$ b-baryon), as described in the note "Production and Decay of b-Flavored Hadrons."

For inclusive branching fractions, *e.g.*, $\Lambda_b \to \overline{\Lambda}_c$anything, the values usually are multiplicities, not branching fractions. They can be greater than one.

Λ_b^0 DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$J/\psi(1S)\Lambda \times$ B($b \to \Lambda_b^0$)		$(5.8 \pm 0.8) \times 10^{-5}$		1740
$pD^0\pi^-$		$(6.3 \pm 0.7) \times 10^{-4}$		2370
pD^0K^-		$(4.6 \pm 0.8) \times 10^{-5}$		2269
$pJ/\psi\pi^-$		$(2.6\ ^{+0.5}_{-0.4}) \times 10^{-5}$		1755
$p\pi^-J/\psi,\ J/\psi \to \mu^+\mu^-$		$(1.6 \pm 0.8) \times 10^{-6}$		–
$pJ/\psi K^-$		$(3.2\ ^{+0.6}_{-0.5}) \times 10^{-4}$		1589
$P_c(4380)^+K^-,\ P_c \to pJ/\psi$	[t]	$(2.7 \pm 1.4) \times 10^{-5}$		–
$P_c(4450)^+K^-,\ P_c \to pJ/\psi$	[t]	$(1.3 \pm 0.4) \times 10^{-5}$		–
$\chi_{c1}(1P)pK^-$		$(7.6\ ^{+1.5}_{-1.3}) \times 10^{-5}$		1242
$\chi_{c2}(1P)pK^-$		$(7.9\ ^{+1.6}_{-1.4}) \times 10^{-5}$		1198
$pJ/\psi(1S)\pi^+\pi^-K^-$		$(6.6\ ^{+1.3}_{-1.1}) \times 10^{-5}$		1410

$p\psi(2S)K^-$		$(6.6\ {}^{+1.2}_{-1.0}) \times 10^{-5}$		1063
$\chi_{c1}(3872)pK^-$, $\chi_{c1}(3872) \to J/\psi\pi^+\pi^-$		$(1.23\pm0.33) \times 10^{-6}$		–
$\psi(2S)p\pi^-$		$(7.5\ {}^{+1.6}_{-1.4}) \times 10^{-6}$		1320
$p\overline{K}^0\pi^-$		$(1.3\ \pm0.4) \times 10^{-5}$		2693
pK^0K^-		$< 3.5 \times 10^{-6}$	CL=90%	2639
$\Lambda_c^+\pi^-$		$(4.9\ \pm0.4) \times 10^{-3}$	S=1.2	2342
$\Lambda_c^+K^-$		$(3.59\pm0.30) \times 10^{-4}$	S=1.2	2314
$\Lambda_c^+D^-$		$(4.6\ \pm0.6) \times 10^{-4}$		1886
$\Lambda_c^+D_s^-$		(1.10 ± 0.10) %		1833
$\Lambda_c^+\pi^+\pi^-\pi^-$		$(7.7\ \pm1.1) \times 10^{-3}$	S=1.1	2323
$\Lambda_c(2595)^+\pi^-$, $\Lambda_c(2595)^+ \to \Lambda_c^+\pi^+\pi^-$		$(3.4\ \pm1.5) \times 10^{-4}$		2210
$\Lambda_c(2625)^+\pi^-$, $\Lambda_c(2625)^+ \to \Lambda_c^+\pi^+\pi^-$		$(3.3\ \pm1.3) \times 10^{-4}$		2193
$\Sigma_c(2455)^0\pi^+\pi^-$, $\Sigma_c^0 \to \Lambda_c^+\pi^-$		$(5.7\ \pm2.2) \times 10^{-4}$		2265
$\Sigma_c(2455)^{++}\pi^-\pi^-$, $\Sigma_c^{++} \to \Lambda_c^+\pi^+$		$(3.2\ \pm1.6) \times 10^{-4}$		2265
$\Lambda_c^+p\overline{p}\pi^-$		$(2.65\pm0.29) \times 10^{-4}$		1805
$\Sigma_c(2455)^0p\overline{p}$, $\Sigma_c(2455)^0 \to \Lambda_c^+\pi^-$		$(2.4\ \pm0.5) \times 10^{-5}$		–
$\Sigma_c(2520)^0p\overline{p}$, $\Sigma_c(2520)^0 \to \Lambda_c^+\pi^-$		$(3.2\ \pm0.7) \times 10^{-5}$		–
$\Lambda_c^+\ell^-\overline{\nu}_\ell$ anything	[u]	$(10.9\ \pm2.2)$ %		–
$\Lambda_c^+\ell^-\overline{\nu}_\ell$		$(6.2\ {}^{+1.4}_{-1.3})$ %		2345
$\Lambda_c^+\pi^+\pi^-\ell^-\overline{\nu}_\ell$		$(5.6\ \pm3.1)$ %		2335
$\Lambda_c(2595)^+\ell^-\overline{\nu}_\ell$		$(7.9\ {}^{+4.0}_{-3.5}) \times 10^{-3}$		2212
$\Lambda_c(2625)^+\ell^-\overline{\nu}_\ell$		$(1.3\ {}^{+0.6}_{-0.5})$ %		2195
ph^-	[v]	$< 2.3 \times 10^{-5}$	CL=90%	2730
$p\pi^-$		$(4.5\ \pm0.8) \times 10^{-6}$		2730
pK^-		$(5.4\ \pm1.0) \times 10^{-6}$		2709
pD_s^-		$< 4.8 \times 10^{-4}$	CL=90%	2364
$p\mu^-\overline{\nu}_\mu$		$(4.1\ \pm1.0) \times 10^{-4}$		2730
$\Lambda\mu^+\mu^-$		$(1.08\pm0.28) \times 10^{-6}$		2695
$p\pi^-\mu^+\mu^-$		$(6.9\ \pm2.5) \times 10^{-8}$		2720
$\Lambda\gamma$		$(7.1\ \pm1.7) \times 10^{-6}$		2699
$\Lambda\eta$		$(9\ {}^{+7}_{-5}) \times 10^{-6}$		2670
$\Lambda\eta'(958)$		$< 3.1 \times 10^{-6}$	CL=90%	2611
$\Lambda\pi^+\pi^-$		$(4.7\ \pm1.9) \times 10^{-6}$		2692
$\Lambda K^+\pi^-$		$(5.7\ \pm1.3) \times 10^{-6}$		2660
ΛK^+K^-		$(1.62\pm0.23) \times 10^{-5}$		2605
$\Lambda\phi$		$(9.8\ \pm2.6) \times 10^{-6}$		2599
$p\pi^-\pi^+\pi^-$		$(2.11\pm0.23) \times 10^{-5}$		2715
$pK^-K^+\pi^-$		$(4.1\ \pm0.6) \times 10^{-6}$		2612
$pK^-\pi^+\pi^-$		$(5.1\ \pm0.5) \times 10^{-5}$		2675
$pK^-K^+K^-$		$(1.27\pm0.14) \times 10^{-5}$		2524

See Particle Listings for 1 decay modes that have been seen / not seen.

$\Lambda_b(5912)^0$

$J^P = \frac{1}{2}^-$

Mass $m = 5912.20 \pm 0.21$ MeV
Full width $\Gamma < 0.66$ MeV, CL = 90%

$\Lambda_b(5920)^0$

$J^P = \frac{3}{2}^-$

Mass $m = 5919.92 \pm 0.19$ MeV (S = 1.1)
Full width $\Gamma < 0.63$ MeV, CL = 90%

$\Lambda_b(6146)^0$

$J^P = \frac{3}{2}^+$

Mass $m = 6146.2 \pm 0.4$ MeV
Full width $\Gamma = 2.9 \pm 1.3$ MeV
Full width $\Gamma = 526.55 \pm 0.34$ MeV

$\Lambda_b(6152)^0$

$J^P = \frac{5}{2}^+$

Mass $m = 6152.5 \pm 0.4$ MeV
Full width $\Gamma = 2.1 \pm 0.9$ MeV
Full width $\Gamma = 532.89 \pm 0.28$ MeV
Full width $\Gamma = 6.34 \pm 0.32$ MeV

Σ_b

$I(J^P) = 1(\frac{1}{2}^+)$
I, *J*, *P* need confirmation.

Mass $m(\Sigma_b^+) = 5810.56 \pm 0.25$ MeV
Mass $m(\Sigma_b^-) = 5815.64 \pm 0.27$ MeV
$m_{\Sigma_b^+} - m_{\Sigma_b^-} = -5.06 \pm 0.18$ MeV
$\Gamma(\Sigma_b^+) = 5.0 \pm 0.5$ MeV
$\Gamma(\Sigma_b^-) = 5.3 \pm 0.5$ MeV

Σ_b DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Lambda_b^0 \pi$	dominant	133

Σ_b^*

$I(J^P) = 1(\frac{3}{2}^+)$
I, *J*, *P* need confirmation.

Mass $m(\Sigma_b^{*+}) = 5830.32 \pm 0.27$ MeV
Mass $m(\Sigma_b^{*-}) = 5834.74 \pm 0.30$ MeV
$m_{\Sigma_b^{*+}} - m_{\Sigma_b^{*-}} = -4.37 \pm 0.33$ MeV (S = 1.6)
$m_{\Sigma_b^{*+}} - m_{\Sigma_b^+} = 19.73 \pm 0.18$
$m_{\Sigma_b^{*-}} - m_{\Sigma_b^-} = 19.09 \pm 0.22$
$\Gamma(\Sigma_b^{*+}) = 9.4 \pm 0.5$ MeV
$\Gamma(\Sigma_b^{*-}) = 10.4 \pm 0.8$ MeV (S = 1.3)
$m_{\Sigma_b^*} - m_{\Sigma_b} = 21.2 \pm 2.0$ MeV

Σ_b^* DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Lambda_b^0\pi$	dominant	159

$\Sigma_b(6097)^+$

$J^P = ?^?$

Mass $m = 6095.8 \pm 1.7$ MeV
Full width $\Gamma = 31 \pm 6$ MeV

$\Sigma_b(6097)^-$

$J^P = ?^?$

Mass $m = 6098.0 \pm 1.8$ MeV
Full width $\Gamma = 29 \pm 4$ MeV

Ξ_b^0, Ξ_b^-

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$
I, J, P need confirmation.

$m(\Xi_b^-) = 5797.0 \pm 0.6$ MeV (S = 1.7)
$m(\Xi_b^0) = 5791.9 \pm 0.5$ MeV
$m_{\Xi_b^-} - m_{\Lambda_b^0} = 177.5 \pm 0.5$ MeV (S = 1.6)
$m_{\Xi_b^0} - m_{\Lambda_b^0} = 172.5 \pm 0.4$ MeV
$m_{\Xi_b^-} - m_{\Xi_b^0} = 5.9 \pm 0.6$ MeV
Mean life $\tau_{\Xi_b^-} = (1.572 \pm 0.040) \times 10^{-12}$ s
Mean life $\tau_{\Xi_b^0} = (1.480 \pm 0.030) \times 10^{-12}$ s

Ξ_b DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\Xi^- \ell^- \overline{\nu}_\ell X \times$ B($\overline{b} \to \Xi_b$)	$(3.9 \pm 1.2) \times 10^{-4}$	S=1.4	–
$J/\psi \Xi^- \times$ B($b \to \Xi_b^-$)	$(1.02^{+0.26}_{-0.21}) \times 10^{-5}$		1782
$J/\psi \Lambda K^- \times$ B($b \to \Xi_b^-$)	$(2.5 \pm 0.4) \times 10^{-6}$		1631
$p D^0 K^- \times$ B($\overline{b} \to \Xi_b$)	$(1.7 \pm 0.6) \times 10^{-6}$		2374
$p \overline{K}^0 \pi^- \times$ B($\overline{b} \to \Xi_b$)/B($\overline{b} \to B^0$)	$< 1.6 \times 10^{-6}$	CL=90%	2783
$p K^0 K^- \times$ B($\overline{b} \to \Xi_b$)/B($\overline{b} \to B^0$)	$< 1.1 \times 10^{-6}$	CL=90%	2730
$p K^- K^- \times$ B($\overline{b} \to \Xi_b$)	$(3.7 \pm 0.8) \times 10^{-8}$		2731
$\Lambda \pi^+ \pi^- \times$ B($b \to \Xi_b^0$)/B($b \to \Lambda_b^0$)	$< 1.7 \times 10^{-6}$	CL=90%	2781
$\Lambda K^- \pi^+ \times$ B($b \to \Xi_b^0$)/B($b \to \Lambda_b^0$)	$< 8 \times 10^{-7}$	CL=90%	2751
$\Lambda K^+ K^- \times$ B($b \to \Xi_b^0$)/B($b \to \Lambda_b^0$)	$< 3 \times 10^{-7}$	CL=90%	2698
$\Lambda_c^+ K^- \times$ B($\overline{b} \to \Xi_b$)	$(6 \pm 4) \times 10^{-7}$		2416
$\Lambda_b^0 \pi^- \times$ B($b \to \Xi_b^-$)/B($b \to \Lambda_b^0$)	$(5.7 \pm 2.0) \times 10^{-4}$		99
$p K^- \pi^+ \pi^- \times$ B($b \to \Xi_b^0$)/B($b \to \Lambda_b^0$)	$(1.9 \pm 0.4) \times 10^{-6}$		2766
$p K^- K^- \pi^+ \times$ B($b \to \Xi_b^0$)/B($b \to \Lambda_b^0$)	$(1.73 \pm 0.32) \times 10^{-6}$		2704
$p K^- K^+ K^- \times$ B($b \to \Xi_b^0$)/B($b \to \Lambda_b^0$)	$(1.8 \pm 1.0) \times 10^{-7}$		2620

$\Xi'_b(5935)^-$

$J^P = \frac{1}{2}^+$

Mass $m = 5935.02 \pm 0.05$ MeV
$m_{\Xi'_b(5935)^-} - m_{\Xi^0_b} - m_{\pi^-} = 3.653 \pm 0.019$ MeV
Full width $\Gamma < 0.08$ MeV, CL = 95%

$\Xi'_b(5935)^-$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Xi^0_b \pi^- \times$ B($\overline{b} \to \Xi'_b(5935)^-$)/B($\overline{b} \to \Xi^0_b$)	(11.8±1.8) %	31

$\Xi_b(5945)^0$

$J^P = \frac{3}{2}^+$

Mass $m = 5952.3 \pm 0.6$ MeV
Full width $\Gamma = 0.90 \pm 0.18$ MeV

$\Xi_b(5955)^-$

$J^P = \frac{3}{2}^+$

Mass $m = 5955.33 \pm 0.13$ MeV
$m_{\Xi_b(5955)^-} - m_{\Xi^0_b} - m_{\pi^-} = 23.96 \pm 0.13$ MeV
Full width $\Gamma = 1.65 \pm 0.33$ MeV

$\Xi_b(5955)^-$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Xi^0_b \pi^- \times$ B($\overline{b} \to \Xi^*_b(5955)^-$)/B($\overline{b} \to \Xi^0_b$)	(20.7±3.5) %	84

$\Xi_b(6227)$

$J^P = ?^?$

Mass $m = 6226.9 \pm 2.0$ MeV
Full width $\Gamma = 18 \pm 6$ MeV

$\Xi_b(6227)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor	p (MeV/c)
$\Lambda^0_b K^- \times$ B($b \to \Xi_b(6227)$)/B($b \to \Lambda^0_b$)	$(3.20\pm0.35) \times 10^{-3}$		336
$\Xi^0_b \pi^- \times$ B($b \to \Xi_b(6227)$)/B($b \to \Xi^0_b$)	(2.8 ±1.1) %	1.8	398

Ω^-_b

$I(J^P) = 0(\frac{1}{2}^+)$
I, J, P need confirmation.

Mass $m = 6046.1 \pm 1.7$ MeV
$m_{\Omega^-_b} - m_{\Lambda^0_b} = 426.4 \pm 2.2$ MeV
$m_{\Omega^-_b} - m_{\Xi^-_b} = 247.3 \pm 3.2$ MeV
Mean life $\tau = (1.64^{+0.18}_{-0.17}) \times 10^{-12}$ s
$\tau(\Omega^-_b)/\tau(\Xi^-_b)$ mean life ratio $= 1.11 \pm 0.16$

Ω^-_b DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$J/\psi \Omega^- \times$B($b \to \Omega_b$)	$(2.9^{+1.1}_{-0.8}) \times 10^{-6}$		1806
$pK^-K^- \times$B($\overline{b} \to \Omega_b$)	$< 2.5 \times 10^{-9}$	90%	2866

$p\pi^-\pi^- \times B(\overline{b} \to \Omega_b)$	< 1.5	$\times 10^{-8}$	90%	2943
$pK^-\pi^- \times B(\overline{b} \to \Omega_b)$	< 7	$\times 10^{-9}$	90%	2915

b-baryon ADMIXTURE (Λ_b, Ξ_b, Ω_b)

These branching fractions are actually an average over weakly decaying *b*-baryons weighted by their production rates at the LHC, LEP, and Tevatron, branching ratios, and detection efficiencies. They scale with the *b*-baryon production fraction B($b \to$ *b*-baryon).

The branching fractions B(*b*-baryon $\to \Lambda \ell^- \overline{\nu}_\ell$ anything) and B($\Lambda_b^0 \to \Lambda_c^+ \ell^- \overline{\nu}_\ell$ anything) are not pure measurements because the underlying measured products of these with B($b \to$ *b*-baryon) were used to determine B($b \to$ *b*-baryon), as described in the note "Production and Decay of *b*-Flavored Hadrons."

For inclusive branching fractions, *e.g.*, $B \to D^\pm$ anything, the values usually are multiplicities, not branching fractions. They can be greater than one.

b-baryon ADMIXTURE DECAY MODES (Λ_b,Ξ_b,Ω_b)	Fraction (Γ_i/Γ)	p (MeV/c)
$p\mu^-\overline{\nu}$ anything	$(5.8^{+2.3}_{-2.0})$ %	–
$p\ell\overline{\nu}_\ell$ anything	(5.6 ± 1.2) %	–
p anything	(70 ± 22) %	–
$\Lambda\ell^-\overline{\nu}_\ell$ anything	(3.8 ± 0.6) %	–
$\Lambda\ell^+\nu_\ell$ anything	(3.2 ± 0.8) %	–
Λ anything	(39 ± 7) %	–
$\Xi^-\ell^-\overline{\nu}_\ell$ anything	$(6.6 \pm 1.6) \times 10^{-3}$	–

NOTES

This Summary Table only includes established baryons. The Particle Listings include evidence for other baryons. The masses, widths, and branching fractions for the resonances in this Table are Breit-Wigner parameters, but pole positions are also given for most of the N and Δ resonances.

For most of the resonances, the parameters come from various partial-wave analyses of more or less the same sets of data, and it is not appropriate to treat the results of the analyses as independent or to average them together.

When a quantity has "(S = ...)" to its right, the error on the quantity has been enlarged by the "scale factor" S, defined as $S = \sqrt{\chi^2/(N-1)}$, where N is the number of measurements used in calculating the quantity.

A decay momentum p is given for each decay mode. For a 2-body decay, p is the momentum of each decay product in the rest frame of the decaying particle. For a 3-or-more-body decay, p is the largest momentum any of the products can have in this frame. For any resonance, the *nominal* mass is used in calculating p.

[*a*] The masses of the p and n are most precisely known in u (unified atomic mass units). The conversion factor to MeV, 1 u = 931.494061(21) MeV, is less well known than are the masses in u.

[*b*] The $|m_p - m_{\overline{p}}|/m_p$ and $|q_p + q_{\overline{p}}|/e$ are not independent, and both use the more precise measurement of $|q_{\overline{p}}/m_{\overline{p}}|/(q_p/m_p)$.

[*c*] The limit is from neutrality-of-matter experiments; it assumes $q_n = q_p + q_e$. See also the charge of the neutron.

[*d*] The μp and ep values for the charge radius are much too different to average them. The disagreement is not yet understood.

[*e*] There is a lot of disagreement about the value of the proton magnetic charge radius. See the Listings.

[*f*] The first limit is for $p \to$ anything or "disappearance" modes of a bound proton. The second entry, a rough range of limits, assumes the dominant decay modes are among those investigated. For antiprotons the best limit, inferred from the observation of cosmic ray $\overline{p}$'s is $\tau_{\overline{p}} > 10^7$ yr, the cosmic-ray storage time, but this limit depends on a number of assumptions. The best direct observation of stored antiprotons gives $\tau_{\overline{p}}/\mathrm{B}(\overline{p} \to e^- \gamma) > 7 \times 10^5$ yr.

[*g*] There is some controversy about whether nuclear physics and model dependence complicate the analysis for bound neutrons (from which the best limit comes). The first limit here is from reactor experiments with free neutrons.

[*h*] Lee and Yang in 1956 proposed the existence of a mirror world in an attempt to restore global parity symmetry—thus a search for oscillations between the two worlds. Oscillations between the worlds would be maximal when the magnetic fields B and B' were equal. The limit for any B' in the range 0 to 12.5 μT is >12 s (95% CL).

[*i*] The parameters g_A, g_V, and g_{WM} for semileptonic modes are defined by $\overline{B}_f[\gamma_\lambda(g_V + g_A\gamma_5) + i(g_{WM}/m_{B_i})\ \sigma_{\lambda\nu}\ q^\nu]B_i$, and ϕ_{AV} is defined by $g_A/g_V = |g_A/g_V|e^{i\phi_{AV}}$. See the "Note on Baryon Decay Parameters" in the neutron Particle Listings in the Full *Review of Particle Physics*.

[*j*] Time-reversal invariance requires this to be 0° or 180°.

[*k*] This coefficient is zero if time invariance is not violated.

[*l*] This limit is for γ energies between 0.4 and 782 keV.

[*n*] The decay parameters γ and Δ are calculated from α and ϕ using

$$\gamma = \sqrt{1-\alpha^2}\ \cos\phi\,, \qquad \tan\Delta = -\frac{1}{\alpha}\ \sqrt{1-\alpha^2}\ \sin\phi\,.$$

See the "Note on Baryon Decay Parameters" in the neutron Particle Listings in the Full *Review of Particle Physics*.

[*o*] See Particle Listings in the Full *Review of Particle Physics* for the pion momentum range used in this measurement.

[*p*] Our estimate. See the Particle Listings for details.

[*q*] A theoretical value using QED.

[*r*] This branching fraction includes all the decay modes of the final-state resonance.

[*s*] See AALTONEN 11H, Fig. 8, for the calculated ratio of $\Lambda_c^+ \pi^0 \pi^0$ and $\Lambda_c^+ \pi^+ \pi^-$ partial widths as a function of the $\Lambda_c(2595)^+ - \Lambda_c^+$ mass difference. At our value of the mass difference, the ratio is about 4.

[*t*] P_c^+ is a pentaquark-charmonium state.

[*u*] Not a pure measurement. See note at head of Λ_b^0 Decay Modes.

[*v*] Here h^- means π^- or K^-.

SEARCHES
not in other sections

Magnetic Monopole Searches

The most sensitive experiments obtain negative results.

Best cosmic-ray supermassive monopole flux limit:

$< 1.4 \times 10^{-16}$ cm^{-2}sr^{-1}s^{-1} for $1.1 \times 10^{-4} < \beta < 1$

Supersymmetric Particle Searches

All supersymmetric mass bounds here are model dependent.

The limits assume:

1) $\widetilde{\chi}_1^0$ is the lightest supersymmetric particle; 2) R-parity is conserved, unless stated otherwise;

See the Particle Listings in the Full *Review of Particle Physics* for a Note giving details of supersymmetry.

$\widetilde{\chi}_i^0$ — neutralinos (mixtures of $\widetilde{\gamma}$, $\widetilde{Z}^0$, and $\widetilde{H}_i^0$)

Mass $m_{\widetilde{\chi}_1^0} > 0$ GeV, CL = 95%
[general MSSM, non-universal gaugino masses]

Mass $m_{\widetilde{\chi}_1^0} > 46$ GeV, CL = 95%
[all tanβ, all m_0, all $m_{\widetilde{\chi}_2^0} - m_{\widetilde{\chi}_1^0}$]

Mass $m_{\widetilde{\chi}_2^0} > 62.4$ GeV, CL = 95%
[1<tanβ <40, all m_0, all $m_{\widetilde{\chi}_2^0} - m_{\widetilde{\chi}_1^0}$]

Mass $m_{\widetilde{\chi}_3^0} > 99.9$ GeV, CL = 95%
[1<tanβ <40, all m_0, all $m_{\widetilde{\chi}_2^0} - m_{\widetilde{\chi}_1^0}$]

Mass $m_{\widetilde{\chi}_4^0} > 116$ GeV, CL = 95%
[1<tanβ <40, all m_0, all $m_{\widetilde{\chi}_2^0} - m_{\widetilde{\chi}_1^0}$]

$\widetilde{\chi}_i^\pm$ — charginos (mixtures of $\widetilde{W}^\pm$ and $\widetilde{H}_i^\pm$)

Mass $m_{\widetilde{\chi}_1^\pm} > 94$ GeV, CL = 95%
[tan$\beta < 40$, $m_{\widetilde{\chi}_1^\pm} - m_{\widetilde{\chi}_1^0} > 3$ GeV, all m_0]

Mass $m_{\widetilde{\chi}_1^\pm} > 810$ GeV, CL = 95%
[$\ell^\pm \ell^\mp$, Tchi1chi1C, $m_{\widetilde{\chi}_1^0} = 0$ GeV]

$\widetilde{\chi}^\pm$ — long-lived chargino

Mass $m_{\widetilde{\chi}^\pm} > 620$ GeV, CL = 95% [stable $\widetilde{\chi}^\pm$]

$\widetilde{\nu}$ — sneutrino

Mass $m >$ 41 GeV, CL = 95% [model independent]

Mass $m >$ 94 GeV, CL = 95%
[CMSSM, $1 \leq \tan\beta \leq 40$, $m_{\widetilde{e}_R} - m_{\widetilde{\chi}_1^0} > 10$ GeV]

Mass $m >$ 3400 GeV, CL = 95% [R-Parity Violating]
[$\widetilde{\nu}_\tau \rightarrow e\mu$, $\lambda_{312} = \lambda_{321} = 0.07$, $\lambda'_{311} = 0.11$]

$\widetilde{e}$ — scalar electron (selectron)

Mass $m(\widetilde{e}_L) >$ 107 GeV, CL = 95% [all $m_{\widetilde{e}_L} - m_{\widetilde{\chi}^0_1}$]

Mass $m >$ 410 GeV, CL = 95% [R-Parity Violating]

[$\geq 4\ell^{\pm}$, $\widetilde{\ell} \rightarrow l\widetilde{\chi}^0_1$, $\widetilde{\chi}^0_1 \rightarrow \ell^{\pm}\ell^{\mp}\nu$]

$\widetilde{\mu}$ — scalar muon (smuon)

Mass $m >$ 94 GeV, CL = 95%

[CMSSM, $1 \leq \tan\beta \leq 40$, $m_{\widetilde{\mu}_R} - m_{\widetilde{\chi}^0_1} > 10$ GeV]

Mass $m >$ 410 GeV, CL = 95% [R-Parity Violating]

[$\geq 4\ell^{\pm}$, $\widetilde{\ell} \rightarrow l\widetilde{\chi}^0_1$, $\widetilde{\chi}^0_1 \rightarrow \ell^{\pm}\ell^{\mp}\nu$]

$\widetilde{\tau}$ — scalar tau (stau)

Mass $m >$ 81.9 GeV, CL = 95%

[$m_{\widetilde{\tau}_R} - m_{\widetilde{\chi}^0_1}$ >15 GeV, all θ_τ, B($\widetilde{\tau} \rightarrow \tau\widetilde{\chi}^0_1$) = 100%]

Mass $m >$ 286 GeV, CL = 95% [long-lived $\widetilde{\tau}$]

$\widetilde{q}$ – squarks of the first two quark generations

Mass $m >$ 1.450×10^3 GeV, CL = 95%

[CMSSM, $\tan\beta = 30$, $A_0 = -2\max(m_0, m_{1/2})$, $\mu > 0$]

Mass $m >$ 1630 GeV, CL = 95%

[mass degenerate squarks]

Mass $m >$ 1130 GeV, CL = 95%

[single light squark bounds]

Mass $m >$ 1.600×10^3 GeV, CL = 95% [R-Parity Violating]

[$\widetilde{q} \rightarrow q\widetilde{\chi}^0_1$, $\widetilde{\chi}^0_1 \rightarrow \ell\ell\nu$, λ_{121},$\lambda_{122} \neq 0$, $m_{\widetilde{g}}$=2400GeV]

$\widetilde{q}$ — long-lived squark

Mass $m >$ 1340, CL = 95% [$\widetilde{t}$ R-hadrons]

Mass $m >$ 1250, CL = 95% [$\widetilde{b}$ R-hadrons]

$\widetilde{b}$ — scalar bottom (sbottom)

Mass $m >$ 1230 GeV, CL = 95%

[jets+$\not\!\!E_T$, Tsbot1, $m_{\widetilde{\chi}^0_1} = 0$ GeV]

Mass $m >$ 307 GeV, CL = 95% [R-Parity Violating]

[$\widetilde{b} \rightarrow td$ or ts, λ''_{332} or λ''_{331} coupling]

$\widetilde{t}$ — scalar top (stop)

Mass $m >$ 1190 GeV, CL = 95%

[jets+$\not\!\!E_T$, Tstop1, $m_{\widetilde{\chi}^0_1} = 0$ GeV]

Mass $m >$ 1100 GeV, CL = 95% [R-Parity Violating]

[$\widetilde{t} \rightarrow be$, Tstop2RPV, prompt]

$\widetilde{g}$ — gluino

Mass $m >$ 2.000×10^3 GeV, CL = 95%

[jets + $\not\!\!E_T$, Tglu1A, $m_{\widetilde{\chi}^0_1} = 0$ GeV]

Mass $m >$ 2.260×10^3 GeV, CL = 95% [R-Parity Violating]

[$\geq 4\ell$, $\lambda_{12k} \neq 0$, $m_{\widetilde{\chi}^0_1} > 1000$ GeV]

Technicolor

The limits for technicolor (and top-color) particles are quite varied depending on assumptions. See the Technicolor section of the full *Review* (the data listings).

Quark and Lepton Compositeness, Searches for

Scale Limits Λ for Contact Interactions (the lowest dimensional interactions with four fermions)

If the Lagrangian has the form

$$\pm \frac{g^2}{2\Lambda^2}\, \overline{\psi}_L \gamma_\mu \psi_L \overline{\psi}_L \gamma^\mu \psi_L$$

(with $g^2/4\pi$ set equal to 1), then we define $\Lambda \equiv \Lambda^{\pm}_{LL}$. For the full definitions and for other forms, see the Note in the Listings on Searches for Quark and Lepton Compositeness in the full *Review* and the original literature.

$\Lambda^{+}_{LL}(eeee)$	$>$ 8.3 TeV, CL = 95%
$\Lambda^{-}_{LL}(eeee)$	$>$ 10.3 TeV, CL = 95%
$\Lambda^{+}_{LL}(ee\mu\mu)$	$>$ 8.5 TeV, CL = 95%
$\Lambda^{-}_{LL}(ee\mu\mu)$	$>$ 9.5 TeV, CL = 95%
$\Lambda^{+}_{LL}(ee\tau\tau)$	$>$ 7.9 TeV, CL = 95%
$\Lambda^{-}_{LL}(ee\tau\tau)$	$>$ 7.2 TeV, CL = 95%
$\Lambda^{+}_{LL}(\ell\ell\ell\ell)$	$>$ 9.1 TeV, CL = 95%
$\Lambda^{-}_{LL}(\ell\ell\ell\ell)$	$>$ 10.3 TeV, CL = 95%
$\Lambda^{+}_{LL}(eeqq)$	$>$ 24 TeV, CL = 95%
$\Lambda^{-}_{LL}(eeqq)$	$>$ 37 TeV, CL = 95%
$\Lambda^{+}_{LL}(eeuu)$	$>$ 23.3 TeV, CL = 95%
$\Lambda^{-}_{LL}(eeuu)$	$>$ 12.5 TeV, CL = 95%
$\Lambda^{+}_{LL}(eedd)$	$>$ 11.1 TeV, CL = 95%
$\Lambda^{-}_{LL}(eedd)$	$>$ 26.4 TeV, CL = 95%
$\Lambda^{+}_{LL}(eecc)$	$>$ 9.4 TeV, CL = 95%
$\Lambda^{-}_{LL}(eecc)$	$>$ 5.6 TeV, CL = 95%
$\Lambda^{+}_{LL}(eebb)$	$>$ 9.4 TeV, CL = 95%
$\Lambda^{-}_{LL}(eebb)$	$>$ 10.2 TeV, CL = 95%
$\Lambda^{+}_{LL}(\mu\mu qq)$	$>$ 20 TeV, CL = 95%
$\Lambda^{-}_{LL}(\mu\mu qq)$	$>$ 30 TeV, CL = 95%
$\Lambda(\ell\nu\ell\nu)$	$>$ 3.10 TeV, CL = 90%
$\Lambda(e\nu qq)$	$>$ 2.81 TeV, CL = 95%
$\Lambda^{+}_{LL}(qqqq)$	$>$ 13.1 none 17.4–29.5 TeV, CL = 95%
$\Lambda^{-}_{LL}(qqqq)$	$>$ 21.8 TeV, CL = 95%

$\Lambda^{+}_{LL}(\nu\nu qq)$ > 5.0 TeV, CL = 95%

$\Lambda^{-}_{LL}(\nu\nu qq)$ > 5.4 TeV, CL = 95%

Excited Leptons

The limits from $\ell^{*+}\ell^{*-}$ do not depend on λ (where λ is the $\ell\ell^*$ transition coupling). The λ-dependent limits assume chiral coupling.

$e^{*\pm}$ — excited electron

Mass $m >$ 103.2 GeV, CL = 95% (from $e^* e^*$)
Mass $m >$ 4.800×10^3 GeV, CL = 95% (from $e e^*$)
Mass $m >$ 356 GeV, CL = 95% (if $\lambda_\gamma = 1$)

$\mu^{*\pm}$ — excited muon

Mass $m >$ 103.2 GeV, CL = 95% (from $\mu^* \mu^*$)
Mass $m >$ 3.800×10^3 GeV, CL = 95% (from $\mu\mu^*$)

$\tau^{*\pm}$ — excited tau

Mass $m >$ 103.2 GeV, CL = 95% (from $\tau^* \tau^*$)
Mass $m >$ 2.500×10^3 GeV, CL = 95% (from $\tau\tau^*$)

ν^* — excited neutrino

Mass $m >$ 1.600×10^3 GeV, CL = 95% (from $\nu^* \nu^*$)
Mass $m >$ 213 GeV, CL = 95% (from $\nu^* X$)

q^* — excited quark

Mass $m >$ 338 GeV, CL = 95% (from $q^* q^*$)
Mass $m >$ 6.000×10^3 GeV, CL = 95% (from $q^* X$)

Color Sextet and Octet Particles

Color Sextet Quarks (q_6)

Mass $m >$ 84 GeV, CL = 95% (Stable q_6)

Color Octet Charged Leptons (ℓ_8)

Mass $m >$ 86 GeV, CL = 95% (Stable ℓ_8)

Color Octet Neutrinos (ν_8)

Mass $m >$ 110 GeV, CL = 90% ($\nu_8 \to \nu g$)

Extra Dimensions

Please refer to the Extra Dimensions section of the full *Review* for a discussion of the model-dependence of these bounds, and further constraints.

Constraints on the radius of the extra dimensions, for the case of two-flat dimensions of equal radii

$R <$ 30 μm, CL = 95% (direct tests of Newton's law)
$R <$ 4.8 μm, CL = 95% ($pp \to jG$)
$R <$ 0.16–916 nm (astrophysics; limits depend on technique and assumptions)

Constraints on the fundamental gravity scale

M_{TT} > 9.02 TeV, CL = 95% ($pp \to$ dijet, angular distribution)
M_c > 4.16 TeV, CL = 95% ($pp \to \ell\overline{\ell}$)

Constraints on the Kaluza-Klein graviton in warped extra dimensions

M_G > 4.25 TeV, CL = 95% $(pp \to \gamma\gamma)$

Constraints on the Kaluza-Klein gluon in warped extra dimensions

$M_{g_{KK}}$ > 3.8 TeV, CL = 95% $(g_{KK} \to t\overline{t})$

WIMP and Dark Matter Searches

No confirmed evidence found for galactic WIMPs from the GeV to the TeV mass scales and down to 1×10^{-10} pb spin independent cross section at M = 100 GeV.

Tests of Conservation Laws

Revised March 2020 by A. Pich (IFIC, Valencia) and M. Ramsey-Musolf (Tsung-Dao Lee Inst.; SJTU; U. Massachusetts).

The following text discusses the best limits among those included in the full Review, where more complete details can be found. Unless otherwise specified, all limits quoted here are given at a C.L. of 90%.

DISCRETE SPACE-TIME SYMMETRIES

Charge conjugation (C), parity (P) and time reversal (T) are empirically found to be symmetries of the electromagnetic (QED) and strong (QCD) interactions, but they are violated by the weak forces. The product of the three discrete symmetries, CPT, is an exact symmetry of any local and Lorentz-invariant quantum field theory with a positive-definite Hermitian Hamiltonian that preserves micro-causality.

1 Violations of CP and T

The first evidence of CP non-invariance in particle physics was the observation in 1964 of $K^0_L \to \pi^+\pi^-$ decays. The non-zero ratio $|\eta_{+-}| \equiv |\mathcal{M}(K^0_L \to \pi^+\pi^-)/\mathcal{M}(K^0_S \to \pi^+\pi^-)| = (2.232 \pm 0.011) \times 10^{-3}$ could be explained as a K^0–$\overline{K}^0$ mixing effect ($\eta_{+-} = \epsilon$), which would imply an identical ratio $\eta_{00} \equiv \mathcal{M}(K^0_L \to \pi^0\pi^0)/\mathcal{M}(K^0_S \to \pi^0\pi^0)$ in the neutral decay mode and successfully predicts the observed CP-violating semileptonic asymmetry $[\Gamma(K^0_L \to \pi^- e^+ \nu_e) - \Gamma(K^0_L \to \pi^+ e^- \bar{\nu}_e)]/[\mathrm{sum}] = (3.34 \pm 0.07) \times 10^{-3}$. A tiny difference between η_{+-} and η_{00} was reported for the first time in 1988 by the CERN NA31 experiment, and later established at the 7.2σ level with the full data samples from the NA31, E731, NA48 and KTeV experiments: $\mathrm{Re}(\epsilon'/\epsilon) = \frac{1}{3}\,(1 - |\eta_{00}/\eta_{+-}|) = (1.66 \pm 0.23) \times 10^{-3}$. This important measurement confirmed that CP violation is associated with a $\Delta S = 1$ transition, as predicted by the CKM mechanism. The Standard Model (SM) prediction, $\mathrm{Re}(\epsilon'/\epsilon) = (1.4 \pm 0.5) \times 10^{-3}$, is in good agreement with the measured ratio, although the theoretical uncertainty is unfortunately large.

Much larger CP asymmetries have been later measured in B meson decays, many of them involving the interference between B^0–$\overline{B}^0$ mixing and the decay amplitude. They provide many successful tests of the CKM unitarity structure, validating the SM mechanism of CP violation (see the review on CP violation in the quark sector). Prominent signals of direct CP violation have been also clearly established in several $B^\pm$, B^0_d and B^0_s decays, and, very recently, in charm decays.

While CP violation implies a breaking of time-reversal symmetry, direct tests of T violation are much more difficult. The CPLEAR experiment observed longtime ago a non-zero difference between the oscillation probabilities of $K^0 \to \overline{K}^0$ and $\overline{K}^0 \to K^0$. More recently, the exchange of initial and final states has been made possible in B decays, taking advantage of the entanglement of the two daughter mesons produced in the decay $\Upsilon(4S) \to B\bar{B}$ which allows for both flavor ($B^0 \to \ell^+ X$, $\overline{B}^0 \to \ell^- X$) and CP ($B_+ \to J/\psi K^0_L$, $B_- \to J/\psi K^0_S$) tagging. Comparing the rates of the $\overline{B}^0 \to B_\pm$ and $B^0 \to B_\pm$ transitions with their T-reversed $B_\pm \to \overline{B}^0$ and $B_\pm \to B^0$ processes, the BABAR experiment has reported the first direct observation of T violation in the B system, with a significance of 14σ.

Among the most powerful tests of P (CP) and T invariance is the search for a permanent electric dipole moment (EDM) of an elementary fermion or non-degenerate quantum system. No positive signal has been detected so far. The most stringent limits have been obtained for the EDMs of the electron, $|d_e| < 1.1 \times 10^{-29}$, mercury atom, $|d_{\mathrm{Hg}}| < 7.4 \times$

10^{-30} (95% C.L.), and neutron, $|d_n| < 1.8 \times 10^{-26}$ (90% C.L.).

2 Tests of *CPT*

CPT symmetry implies the equality of the masses and widths of a particle and its antiparticle. The most constraining limits are extracted from the neutral kaons: $2\,|m_{K^0} - m_{\overline{K}^0}|/(m_{K^0} + m_{\overline{K}^0}) < 6 \times 10^{-19}$ and $2\,|\Gamma_{K^0} - \Gamma_{\overline{K}^0}|/(\Gamma_{K^0} + \Gamma_{\overline{K}^0}) = (8 \pm 8) \times 10^{-18}$. The measured masses and electric charges of the electron, the proton and their antiparticles provide also strong limits on *CPT* violation: $2\,|m_{e^+} - m_{e^-}|/(m_{e^+} + m_{e^-}) < 8 \times 10^{-9}$, $|q_{e^+} + q_{e^-}|/e < 4 \times 10^{-8}$ and $|q_{\bar{p}} m_p/(q_p m_{\bar{p}})| - 1 = (0.1 \pm 6.9) \times 10^{-11}$. Worth mentioning are also the tight constraints derived from the lepton and antilepton magnetic moments, $2\,(g_{e^+} - g_{e^-})(g_{e^+} + g_{e^-}) = (-0.5 \pm 2.1) \times 10^{-12}$ and $2\,(g_{\mu^+} - g_{\mu^-})(g_{\mu^+} + g_{\mu^-}) = (-0.11 \pm 0.12) \times 10^{-8}$, those of the proton and antiproton, $(\mu_p + \mu_{\bar{p}})\,/\mu_p = (2 \pm 4) \times 10^{-9}$, and the recent measurement of the 1S-2S atomic transition in antihydrogen which agrees with the corresponding frequency spectral line in hydrogen at a relative precision of 2×10^{-12}.

QUANTUM-NUMBER CONSERVATION LAWS

Conservation laws of several quantum numbers have been empirically established with a high degree of confidence. However, while some of them are deeply rooted in basic principles such as gauge invariance or Lorentz symmetry, others appear to be accidental symmetries of the SM Lagrangian and could be broken by new physics interactions.

3 Electric charge

The conservation of electric charges is associated with the QED gauge symmetry. The most precise tests are the non-observation of the decays $e \to \nu_e \gamma$ ($\tau > 6.6 \times 10^{28}$ yr) and $n \to p \nu_e \bar{\nu}_e$ (Br $< 8 \times 10^{-27}$, 68% C.L.).

4 Lepton family numbers

Neutrino oscillations show that neutrinos have tiny masses and there are sizable mixings among the lepton flavors. Nevertheless, lepton-flavor violation (LFV) in neutrinoless transitions from one charged lepton flavor to another has never been observed. Among the most sensitive probes are searches for the LFV decays of the muon, $\text{Br}(\mu \to e\gamma) < 4.2 \times 10^{-13}$ and $\text{Br}(\mu \to 3e) < 1.0 \times 10^{-12}$, as well as the conversion process $\sigma(\mu^- \text{Au} \to e^- \text{Au})/\sigma(\mu^- \text{Au} \to \text{all}) < 7 \times 10^{-13}$. Stringent limits have been also set on the LFV decay modes of the τ lepton. The large τ data samples collected at the B factories have made possible to reach a 10^{-8} sensitivity for many of its leptonic ($\tau \to \ell\gamma$, $\tau \to \ell' \ell^+ \ell^-$) and semileptonic ($\tau \to \ell P^0$, $\tau \to \ell V^0$, $\tau \to \ell P^0 P^0$, $\tau \to \ell P^+ P'^-$) neutrinoless LFV decays. Interesting limits on LFV are also obtained in meson decays. The best bounds come from kaon experiments, e.g., $\text{Br}(K_L^0 \to e^\pm \mu^\mp) < 4.7 \times 10^{-12}$ and $\text{Br}(K^+ \to \pi^+ \mu^+ e^-) < 1.3 \times 10^{-11}$.

The LFV decays of the Z boson were probed at LEP at the 10^{-5} to 10^{-6} level. The ATLAS collaboration has recently put a stronger bound on the $Z \to e^\pm \mu^\mp$ decay mode: $\text{Br}(Z \to e^\pm \mu^\mp) < 7.5 \times 10^{-7}$ (95% C.L.). LHC is now starting to test LFV in Higgs decays, within the available statistics. The current (95% C.L.) experimental upper bounds, $\text{Br}(H^0 \to e^\pm \mu^\mp) < 6.1 \times 10^{-5}$, $\text{Br}(H^0 \to e^\pm \tau^\mp) < 0.47\%$ and $\text{Br}(H^0 \to \mu^\pm \tau^\mp) < 0.25\%$, constrain the LFV Yukawa couplings of the Higgs boson.

5 Baryon and Lepton Number

Many experiments have searched for B- and/or L-violating transitions, but no positive signal has been identified so far. The neutrinoless double-β decay $(Z, A) \to (Z+2, A) + e^- + e^-$ is a particularly interesting $\Delta L = 2$ process, which could represent a spectacular signal of Majorana neutrinos. The current best limit, $\tau_{1/2} > 1.07 \times 10^{26}$ yr, was obtained by the KamLAND-Zen experiment with ^{136}Xe. Stringent constraints on violations of L have been also set in $\mu^- \to e^+$ conversion in muonic atoms, the best limit being $\sigma(\mu^-\text{Ti} \to e^+\text{Ca})/\sigma(\mu^-\text{Ti} \to \text{all}) < 3.6 \times 10^{-11}$, and at the flavor factories through L-violating decays of the τ lepton and K, D and B mesons, such as $\text{Br}(\tau^- \to e^+\pi^-\pi^-) < 2.0 \times 10^{-8}$, $\text{Br}(K^+ \to \pi^-\mu^+\mu^+) < 4.2 \times 10^{-11}$, $\text{Br}(D^+ \to \pi^-\mu^+\mu^+) < 2.2 \times 10^{-8}$ and $\text{Br}(B^+ \to K^-e^+e^+) < 3.0 \times 10^{-8}$.

Proton decay would be the most relevant violation of B, as it would imply the unstability of matter. The current lower bound on the proton lifetime is 3.6×10^{29} yr. Stronger limits have been set for particular decay modes, such as $\tau(p \to e^+\pi^0) > 1.6 \times 10^{34}$ yr. Another spectacular signal would be n–$\bar{n}$ oscillations; the lower limit on the lifetime of this $\Delta B = 2$ transition is 8.6×10^7 s (2.7×10^8 s) for free (bound) neutrons.

The search for B-violating decays of short-lived particles such as Z bosons, τ leptons and B mesons provides also relevant constraints. The best limits are $\text{Br}(Z \to pe, p\mu) < 1.8 \times 10^{-6}$ (95% C.L.), $\text{Br}(\tau^- \to \Lambda\pi^-) < 7.2 \times 10^{-8}$ and $\text{Br}(B^+ \to \Lambda e^+) < 3.2 \times 10^{-8}$.

6 Quark flavors

While strong and electromagnetic forces preserve the quark flavor, the charged-current weak interactions generate transitions among the different quark species. Since the SM flavor-changing mechanism is associated with the $W^\pm$ fermionic vertices, the tree-level transitions satisfy a $\Delta F = \Delta Q$ rule where ΔQ denotes the change in charge of the relevant hadrons. The strongest tests on this conservation law have been obtained in kaon decays such as $\text{Br}(K^+ \to \pi^+\pi^+e^-\bar{\nu}_e) < 1.3 \times 10^{-8}$, and $(\text{Re}\, x, \text{Im}\, x) = (-0.002\pm0.006, 0.0012\pm0.0021)$ where $x \equiv \mathcal{M}(\overline{K}^0 \to \pi^-\ell^+\nu)/\mathcal{M}(K^0 \to \pi^-\ell^+\nu)$.

The $\Delta F = \Delta Q$ rule can be violated through quantum loop contributions giving rise to flavor-changing neutral-current transitions (FCNCs). Owing to the GIM mechanism, processes of this type are very suppressed in the SM, which makes them a superb tool in the search for new physics associated with the flavor dynamics. Within the SM itself, these transitions are also sensitive to the heavy-quark mass scales and have played a crucial role identifying the size of the charm (K^0–$\overline{K}^0$ mixing) and top (B^0–$\overline{B}^0$ mixing) masses before the discovery of those quarks. In addition to the well-established $\Delta F = 2$ mixings in neutral K and B mesons, there is now strong evidence for the mixing of the D^0 meson and its antiparticle.

The FCNC kaon decays into lepton-antilepton pairs put stringent constraints on new flavor-changing interactions. The rate $\text{Br}(K_L^0 \to \mu^+\mu^-) = (6.84\pm0.11)\times10^{-9}$ is completely dominated by the 2γ absorptive contribution, leaving very little room for new-physics. Another very clean test of FCNCs will be soon provided by the decay $K^+ \to \pi^+\nu\bar{\nu}$. With a predicted SM branching fraction of $(7.8\pm0.8)\times10^{-11}$, the CERN NA62 experiment is aiming to collect around 100 events. Even more interesting is the CP-violating neutral mode $K_L^0 \to \pi^0\nu\bar{\nu}$, but the current upper bound of 3.0×10^{-9} is still far away from the SM prediction.

The LHC experiments have recently measured $\text{Br}(B_s^0 \to \mu^+\mu^-) = (3.0\pm0.4)\times10^{-9}$, consistent with the SM expectation. At present, there is a lot of interest on the decays $B \to K^{(*)}\ell^+\ell^-$ where sizable discrepancies between the measured data and the SM predictions have been reported. In particular, the LHCb experiment has found the ratios of produced muons versus electrons to be around 2.5σ below the SM predictions, both in $B \to K^*\ell^+\ell^-$ and in $B^+ \to K^+\ell^+\ell^-$, suggesting a significant violation of lepton universality. The current Belle-II measurements of these ratios are consistent with the SM, but they are also compatible with the LHCb results.

9. Quantum Chromodynamics

Revised August 2019 by J. Huston (Michigan State U.), K. Rabbertz (KIT) and G. Zanderighi (MPI Munich).

Our final world average value is:

$$\alpha_s(M_Z^2) = 0.1179 \pm 0.0010\,. \tag{9.25}$$

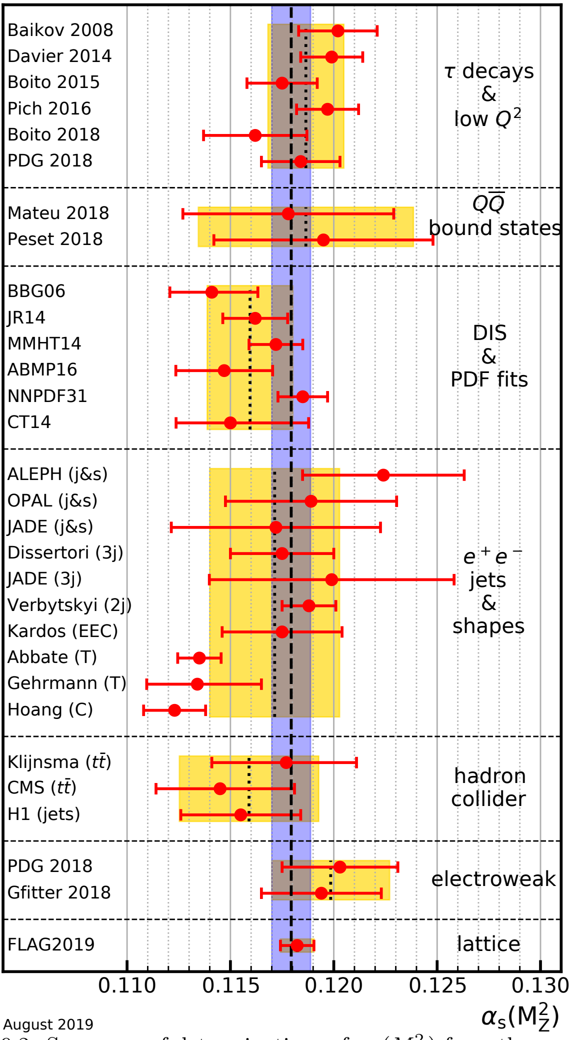


Figure 9.2: Summary of determinations of $\alpha_s(M_Z^2)$ from the seven sub-fields discussed in the text. The yellow (light shaded) bands and dashed lines indicate the pre-average values of each sub-field. The dotted line and grey (dark shaded) band represent the final world average value of $\alpha_s(M_Z^2)$.

10. Electroweak Model and Constraints on New Physics

Revised April 2020 by J. Erler (IF-UNAM; U. of Mainz) and A. Freitas (Pittsburg U.).

The standard model of the electroweak interactions (SM) [1–4] is based on the gauge group SU(2)×U(1), with gauge bosons W_μ^i, $i = 1, 2, 3$, and B_μ for the SU(2) and U(1) factors, respectively, and the corresponding gauge coupling constants g and g'.

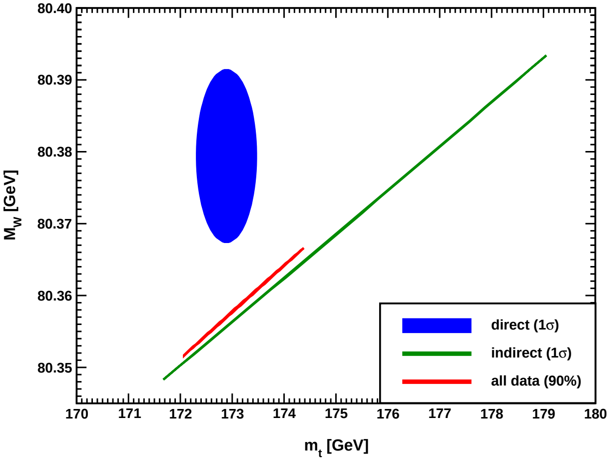


Figure 10.5: One-standard-deviation (39.35%) regions in M_W as a function of m_t for the direct and indirect data, and the 90% CL region ($\Delta\chi^2 = 4.605$) allowed by all data.

Table 10.8: Values of $\hat{s}_Z^2$, s_W^2, α_s, m_t and M_H for various data sets. In the fit to the LHC data, the α_s constraint is from a combined NNLO analysis of inclusive electroweak boson production cross-sections at the LHC [315]. Likewise, for the Tevatron fit we use the α_s result from the inclusive jet cross-section at DØ [316].

data set	$\hat{s}_Z^2$	s_W^2	$\alpha_s(M_Z)$	m_t [GeV]	M_H [GeV]
all data	0.23121(4)	0.22337(10)	0.1185(16)	173.2 ± 0.6	125
all data except M_H	0.23107(9)	0.22309(19)	0.1189(17)	172.9 ± 0.6	$90^{\ 18}_{-16}$
all data except M_Z	0.23111(6)	0.22334(10)	0.1185(16)	172.9 ± 0.6	125
all data except M_W	0.23123(4)	0.22345(11)	0.1189(17)	172.9 ±0.6	125
all data except m_t	0.23113(6)	0.22305(21)	0.1190(17)	176.3 ±1.9	125
$M_{H,Z} + \Gamma_Z + m_t$	0.23126(8)	0.22351(17)	0.1215(47)	172.9 ±0.6	125
LHC	0.23113(10)	0.22337(13)	0.1188(16)	172.7 ±0.6	125
Tevatron + M_Z	0.23102(13)	0.22295(30)	0.1160(44)	174.3 ±0.8	99^{+32}_{-26}
LEP 1 + LEP 2	0.23137(18)	0.22353(46)	0.1235(29)	178 ±11	201^{+279}_{-113}
LEP 1 + SLD	0.23116(17)	0.22348(58)	0.1221(27)	169 ±10	80^{+101}_{-39}
SLD + $M_Z + \Gamma_Z + m_t$	0.23064(28)	0.22227(54)	0.1188(48)	172.9 ±0.6	37^{+30}_{-21}
$A_{FB}^{(b,c)} + M_Z + \Gamma_Z + m_t$	0.23176(27)	0.22467(66)	0.1266(46)	172.9 ±0.6	280^{+145}_{-100}
$M_{W,Z} + \Gamma_{W,Z} + m_t$	0.23103(12)	0.22302(25)	0.1198(44)	172.9 ±0.6	84^{+24}_{-20}
low energy + $M_{H,Z}$	0.23176(94)	0.2254(35)	0.1171(18)	156 ±29	125

Table 10.9: Values of model-independent neutral-current parameters, compared with the SM predictions, where the uncertainties in the latter are $\lesssim$ 0.0001, throughout.

Quantity	Experimental Value	Standard Model	Correlation	
$g_{LV}^{\nu e}$	-0.040 ± 0.015	-0.0398		-0.05
$g_{LA}^{\nu e}$	-0.507 ± 0.014	-0.5064		
$g_{AV}^{eu} + 2\, g_{AV}^{ed}$	0.4927 ± 0.0031	0.4950	-0.88	0.20
$2\, g_{AV}^{eu} - \quad g_{AV}^{ed}$	-0.7165 ± 0.0068	-0.7195		-0.22
$2\, g_{VA}^{eu} - \quad g_{VA}^{ed}$	-0.13 ± 0.06	-0.0954		
g_{VA}^{ee}	0.0190 ± 0.0027	0.0227		

The masses and decay properties of the electroweak bosons and low energy data can be used to search for and set limits on deviations from the SM.

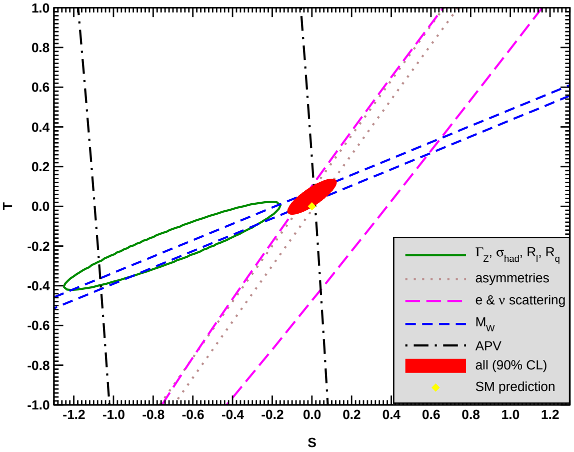


Figure 10.6: 1 σ constraints (39.35% for the closed contours and 68% for the others) on S and T (for $U = 0$) from various inputs combined with M_Z. S and T represent the contributions of new physics only. Data sets not involving M_W or Γ_W are insensitive to U. With the exception of the fit to all data, we fix $\alpha_s = 0.1185$. The black dot indicates the Standard Model values $S = T = 0$.

11. Status of Higgs Boson Physics

Revised December 2019 by M. Carena (FNAL; Chicago U.; Chicago U., Kavli Inst.), C. Grojean (Theoriegruppe, DESY, Hamburg; Physik, Humboldt U.), M. Kado (Rome U. Sapienza; INFN, Rome; U. Paris-Saclay, IJCLab) and V. Sharma (UC San Diego).

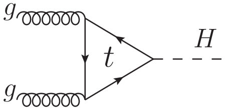
The discovery of the Higgs boson in 2012 confirmed our understanding of the fundamental interactions based on local symmetries spontaneously broken by a non-trivial vacuum structure. It also offered an explanation of the generation of mass in a chiral theory. However, new conundrums about what lies beyond the Standard Model (SM) have come fore.

Since 2012, substantial progress has been made, yielding an increasingly precise profile of the properties of the Higgs boson. New landmark results have been achieved in the direct observation of the couplings of the Higgs boson to the third generation fermions (the $\tau^{\pm}$ and the b and top quarks).

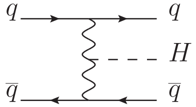
Within the SM, all the production and decay rates of the Higgs boson can be predicted to high accuracy in terms of its mass and of other parameters already known with great accuracy, so the measurements in the Higgs sector appraise the robustness of the SM.

Total SM production cross-section at LHC operating at 13 TeV

$$\sigma_{\rm tot}^{13\,\rm TeV}(H) = 55.1 \pm 2.8\,\rm pb$$

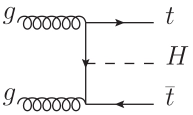


$\sigma(ggH) = 48.6 \pm 2.8\,\rm pb$



$\sigma(\rm VBF) = 3.78 \pm 0.08\,\rm pb$

$\sigma(WH, ZH) = 1.37 \pm 0.03, 0.88 \pm 0.03\,\rm pb$



$\sigma(t\bar{t}H) = 0.50 \pm 0.04\,\rm pb$

Total SM Higgs boson width

$$\Gamma_H = (4.07 \pm 4.0\%)\,\rm MeV$$

Main SM branching ratios and their relative uncertainty

$\mathrm{Br}(H \to b\bar{b}) = (5.82 \pm 1.2\%) \times 10^{-1}$	$\mathrm{Br}(H \to WW) = (2.14 \pm 1.5\%) \times 10^{-1}$
$\mathrm{Br}(H \to \tau\bar{\tau}) = (6.27 \pm 1.6\%) \times 10^{-2}$	$\mathrm{Br}(H \to ZZ) = (2.62 \pm 1.5\%) \times 10^{-2}$
$\mathrm{Br}(H \to \gamma\gamma) = (2.27 \pm 2.1\%) \times 10^{-3}$	$\mathrm{Br}(H \to Z\gamma) = (1.53 \pm 5.8\%) \times 10^{-3}$
$\mathrm{Br}(H \to c\bar{c}) = (2.89 \pm 3.75\%) \times 10^{-2}$	$\mathrm{Br}(H \to \mu\bar{\mu}) = (2.18 \pm 1.7\%) \times 10^{-4}$

Figure: Main leading order Feynman diagrams contributing to the Higgs production at the LHC. The SM predictions for the production cross sections at a centre-of-mass energy of 13 TeV and the branching fractions for the dominant decay modes are indicated assuming a Higgs boson mass of 125 GeV.

The ATLAS and CMS experiments have measured the mass of the Higgs boson in the diphoton and the four-lepton channels at per mille precision, $m_H = 125.10 \pm 0.14$ GeV. The quantum numbers of the Higgs boson have been probed in greater detail and show an excellent consistency with the $J^{PC} = 0^{++}$ hypothesis.

The coupling structure of the Higgs boson has been studied in a large number of channels, in the main production mechanisms at the LHC which are illustrated in the Figure. The Table summarises the ATLAS and CMS measurements and limits on the cross sections times branching ratios, normalised to their SM expectations in the main Higgs analysis channels. Further information on the couplings of the Higgs boson are also obtained from differential cross sections and searches for rare and exotic production and decay modes, including invisible decays.

All measurements are consistent with the SM predictions and provide stringent constraints on a large number of scenarios of new physics.

The review discusses in detail the latest developments in theories extending the SM to solve the fundamental questions raised by the existence of the Higgs boson.

Table: Summary of the ATLAS (A) and CMS (C) measurements of the signal strengths in the various channels (the products of the production rates times the branching ratios normalised to their SM values). Results for the rare modes are reported in the column corresponding to the primary production mode, while the secondary production modes used in the analyses are indicated as "Incl.". Limits on the invisible ("Inv.") as well as $Z\gamma$ and $\gamma^*\gamma$ decays are set at 95% confidence level, and the expected sensitivities are given in parentheses.

Decay mode	ggH	VBF	VH	$t\bar{t}H$
$\gamma\gamma$ (A)	0.96 ± 0.14	$1.39^{+0.40}_{-0.35}$	$1.09^{+0.58}_{-0.54}$	$1.34^{+0.42}_{-0.36}$
$\gamma\gamma$ (C)	1.15 ± 0.15	$0.8^{+0.4}_{-0.3}$	$2.3^{+1.1}_{-1.0}$	$2.27^{+0.86}_{-0.74}$
4ℓ (A)	1.05 ± 0.16	$2.68^{+0.98}_{-0.83}$	$0.68^{+1.20}_{-0.78}$	$1.2^{+1.4}_{-0.8}$
4ℓ (C)	$0.97^{+0.13}_{-0.11}$	$0.64^{+0.48}_{-0.37}$	$1.15^{+0.93}_{-0.74}$	$0.1^{+0.9}_{-0.1}$
WW^* (A)	1.08 ± 0.19	0.59 ± 0.36	3.27 ± 1.84	1.50 ± 0.58
WW^* (C)	$1.35^{+0.21}_{-0.19}$	0.59 ± 0.36	3.27 ± 1.84	1.50 ± 0.58
$\tau^+\tau^-$ (A)	$0.96^{+0.59}_{-0.52}$	$1.16^{+0.58}_{-0.53}$	–	$1.38^{+1.13}_{-0.96}$
$\tau^+\tau^-$ (C)	$0.36^{+0.36}_{-0.37}$	$1.03^{+0.30}_{-0.29}$	-0.33 ± 1.02	0.28 ± 1.02
$b\bar{b}$ (A)	5.8 ± 4.0	2.5 ± 1.3	1.16 ± 0.26	0.79 ± 0.60
$b\bar{b}$ (C)	2.3 ± 1.7	1.3 ± 1.2	1.01 ± 0.22	1.49 ± 0.44
$\mu^+\mu^-$ (A)	0.5 ± 0.7	Incl.	–	–
$\mu^+\mu^-$ (C)	1.0 ± 1.0	–	–	–
$Z\gamma$ (A)	$< 6.6\,(5.2)$	Incl.	–	–
$Z\gamma, \gamma^*\gamma$ (C)	$< 3.9\,(2.0)$	Incl.	Incl.	–
Inv. (A)	–	<37% (28%)	<67% (39%)	–
Inv. (C)	<66% (59%)	<33% (25%)	<40% (42%)	<46% (48%)

12. CKM Quark-Mixing Matrix

Revised March 2020 by A. Ceccucci (CERN), Z. Ligeti (LBNL) and Y. Sakai (KEK).

Highlights from full review.

$$V_{\rm CKM} \equiv V_L^u V_L^{d\dagger} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}. \qquad (12.2)$$

This Cabibbo-Kobayashi-Maskawa (CKM) matrix [1,2] is a 3×3 unitary matrix. It can be parameterized [3] by three mixing angles and the CP-violating KM phase [2].

Motivated by the Wolfenstein parameterization to exhibit the hierarchical structure of the CKM matrix, we define [4–6]

$$s_{12} = \lambda = \frac{|V_{us}|}{\sqrt{|V_{ud}|^2 + |V_{us}|^2}}, \qquad s_{23} = A\lambda^2 = \lambda \left| \frac{V_{cb}}{V_{us}} \right|,$$
$$s_{13} e^{i\delta} = V_{ub}^* = A\lambda^3(\rho + i\eta) = \frac{A\lambda^3(\bar\rho + i\bar\eta)\sqrt{1 - A^2\lambda^4}}{\sqrt{1-\lambda^2}\,[1 - A^2\lambda^4(\bar\rho + i\bar\eta)]}. \qquad (12.4)$$

These ensure that $\bar\rho + i\bar\eta = -(V_{ud}V_{ub}^*)/(V_{cd}V_{cb}^*)$ is phase convention independent, and the CKM matrix written in terms of λ, A, $\bar\rho$, and $\bar\eta$ is unitary to all orders in λ. To $\mathcal{O}(\lambda^4)$ one can write $V_{\rm CKM}$ as

$$V_{\rm CKM} = \begin{pmatrix} 1 - \lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \lambda^2/2 & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4). \qquad (12.5)$$

The unitarity implies $\sum_i V_{ij}V_{ik}^* = \delta_{jk}$ and $\sum_j V_{ij}V_{kj}^* = \delta_{ik}$. The six vanishing combinations can be represented as triangles in a complex plane. The areas of all triangles are the same and are half of the Jarlskog invariant, J [7], which is a phase-convention-independent measure of CP violation, defined by $\mathrm{Im}[V_{ij}V_{kl}V_{il}^*V_{kj}^*] = J\sum_{m,n}\varepsilon_{ikm}\varepsilon_{jln}$. The most commonly used unitarity triangle arises from

$$V_{ud}\,V_{ub}^* + V_{cd}\,V_{cb}^* + V_{td}\,V_{tb}^* = 0, \qquad (12.6)$$

by dividing each side by the best-known one, $V_{cd}V_{cb}^*$ (see Fig. 12.1).

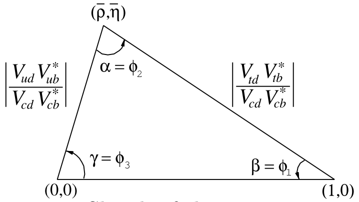


Figure 12.1: Sketch of the unitarity triangle.

The magnitudes of the independently measured CKM elements are

$$V_{\rm CKM} = \begin{pmatrix} 0.97370 \pm 0.00014 & 0.2245 \pm 0.0008 & 0.00382 \pm 0.00024 \\ 0.221 \pm 0.004 & 0.987 \pm 0.011 & 0.0410 \pm 0.0014 \\ 0.0080 \pm 0.0003 & 0.0388 \pm 0.0011 & 1.013 \pm 0.030 \end{pmatrix},$$

and the angles of the unitarity triangle are

$$\sin(2\beta) = 0.699 \pm 0.017, \qquad \alpha = (84.9^{+5.1}_{-4.5})^\circ, \qquad \gamma = (72.1^{+4.1}_{-4.5})^\circ.$$

Using those values, one can check the unitarity of the CKM matrix: $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9985 \pm 0.0005$ (1st row), $|V_{cd}|^2 + |V_{cs}|^2 + |V_{cb}|^2 = 1.025 \pm 0.022$ (2nd row), $|V_{ud}|^2 + |V_{cd}|^2 + |V_{td}|^2 = 0.9970 \pm 0.0018$ (1st column), and $|V_{us}|^2 + |V_{cs}|^2 + |V_{ts}|^2 = 1.026 \pm 0.022$ (2nd column).

12.4 Global fit in the Standard Model

A global fit with three generation unitarity imposed gives

$$\lambda = 0.22650 \pm 0.00048\,, \qquad A = 0.790^{+0.017}_{-0.012}\,,$$
$$\bar\rho = 0.141^{+0.016}_{-0.017}\,, \qquad \bar\eta = 0.357 \pm 0.011\,, \tag{12.26}$$

$$V_{\rm CKM} = \begin{pmatrix} 0.97401 \pm 0.00011 & 0.22650 \pm 0.00048 & 0.00361^{+0.00011}_{-0.00009} \\ 0.22636 \pm 0.00048 & 0.97320 \pm 0.00011 & 0.04053^{+0.00083}_{-0.00061} \\ 0.00854^{+0.00023}_{-0.00016} & 0.03978^{+0.00082}_{-0.00060} & 0.999172^{+0.000024}_{-0.000035} \end{pmatrix}, \tag{12.27}$$

and the Jarlskog invariant of $J = \left(3.00^{+0.15}_{-0.09}\right) \times 10^{-5}$.

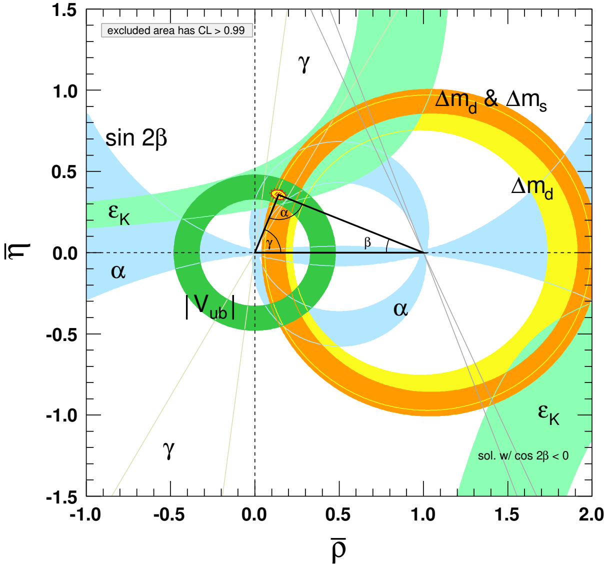


Figure 12.2: Constraints on the $\bar\rho, \bar\eta$ plane from various measurements and the global fit result. The shaded 99% CL regions overlap consistently.

13. CP Violation in the Quark Sector

Revised August 2019 by T. Gershon (Warwick U.) and Y. Nir (Weizmann Inst.).

Within the Standard Model, CP symmetry is broken by complex phases in the Yukawa couplings (that is, the couplings of the Higgs scalar to quarks). When all manipulations to remove unphysical phases in this model are exhausted, one finds that there is a single CP-violating parameter [17]. In the basis of mass eigenstates, this single phase appears in the 3×3 unitary matrix that gives the W-boson couplings to an up-type antiquark and a down-type quark. The beautifully consistent and economical Standard-Model description of CP violation in terms of Yukawa couplings, known as the Kobayashi-Maskawa (KM) mechanism [17], agrees with all measurements to date. Furthermore, one can fit the data allowing new physics contributions to loop processes to compete with, or even dominate over, the Standard Model amplitudes [18,19]. Such analyses provide model-independent proof that the KM phase is different from zero, and that the matrix of three-generation quark mixing is the dominant source of CP violation in meson decays.

The current level of experimental accuracy and the theoretical uncertainties involved in the interpretation of the various observations leave room, however, for additional subdominant sources of CP violation from new physics. Indeed, almost all extensions of the Standard Model imply that there are such additional sources. Moreover, CP violation is a necessary condition for baryogenesis, the process of dynamically generating the matter-antimatter asymmetry of the Universe [20]. Despite the phenomenological success of the KM mechanism, it fails (by several orders of magnitude) to accommodate the observed asymmetry [21]. This discrepancy strongly suggests that Nature provides additional sources of CP violation beyond the KM mechanism. The expectation of new sources motivates the large ongoing experimental effort to find deviations from the predictions of the KM mechanism.

Using the notation M^0 to represent generically one of the K^0, D^0, B^0 or B^0_s particles, we denote the state of an initially pure $|M^0\rangle$ or $|\overline{M}^0\rangle$ after an elapsed proper time t as $|M^0_{\rm phys}(t)\rangle$ or $|\overline{M}^0_{\rm phys}(t)\rangle$, respectively. Defining $x \equiv \Delta m/\Gamma$ and $y \equiv \Delta\Gamma/(2\Gamma)$, where Δm and $\Delta\Gamma$ are the mass and width differences between the two eigenstates of the effective Hamiltonian, $|M_L\rangle \propto p\,|M^0\rangle + q\,|\overline{M}^0\rangle$ and $|M_H\rangle \propto p\,|M^0\rangle - q\,|\overline{M}^0\rangle$, and Γ is their average width, one obtains the following time-dependent rates for decay to a final state f:

$$
\begin{aligned}
&\frac{1}{e^{-\Gamma t}\mathcal{N}_f} d\Gamma\big[M^0_{\rm phys}(t) \to f\big]/dt = \\
&\qquad |A_f|^2 \left\{\left(1+|\lambda_f|^2\right)\cosh(y\Gamma t) + \left(1-|\lambda_f|^2\right)\cos(x\Gamma t) \right. \\
&\qquad \left. +2\,\mathcal{R}e(\lambda_f)\sinh(y\Gamma t) - 2\,\mathcal{I}m(\lambda_f)\sin(x\Gamma t)\right\} , \\
&\frac{1}{e^{-\Gamma t}\mathcal{N}_f} d\Gamma\big[\overline{M}^0_{\rm phys}(t) \to f\big]/dt = \\
&\qquad |(p/q)A_f|^2 \left\{\left(1+|\lambda_f|^2\right)\cosh(y\Gamma t) - \left(1-|\lambda_f|^2\right)\cos(x\Gamma t) \right. \\
&\qquad \left. +2\,\mathcal{R}e(\lambda_f)\sinh(y\Gamma t) + 2\,\mathcal{I}m(\lambda_f)\sin(x\Gamma t)\right\} ,
\end{aligned}
$$

where $\mathcal{N}_f$ is a normalization factor and $\lambda_f = (q/p)(\overline{A}_f/A_f)$ with A_f ($\overline{A}_f$) the amplitude for the M^0 ($\overline{M}^0$) $\to f$ decay. Considering the case that f is a CP eigenstate, we distinguish three types of CP-violating effects that can occur in the quark sector:

I. CP violation in decay, defined by $|\overline{A}_{\overline{f}}/A_f| \neq 1$.
II. CP violation in mixing, defined by $|q/p| \neq 1$.
III. CP violation in interference between decays with and without mixing, defined by $\arg(\lambda_f) \neq 0$.

It is also common to refer to *indirect CP violation* effects, which are consistent with originating from a single CP violating phase in neutral meson mixing, and *direct CP violation* effects, which cannot be explained in this way. CP violation in mixing (type II) is indirect; CP violation in decay (type I) is direct.

Many CP violating observables have been studied by experiments. Here we summarise only a sample of the most important measurements, including some parameters defined using common notation for the asymmetry between $\overline{B}^0_{\rm phys}(t)$ and $B^0_{\rm phys}(t)$ time-dependent decay rates

$$\mathcal{A}_f(t) = S_f \sin(\Delta m t) - C_f \cos(\Delta m t)\,,$$

where $S_f \equiv 2\,\mathcal{I}m(\lambda_f)/\left(1+|\lambda_f|^2\right)$, $C_f \equiv \left(1-|\lambda_f|^2\right)/\left(1+|\lambda_f|^2\right)$.

- Indirect CP violation in $K \to \pi\pi$ and $K \to \pi\ell\nu$ decays, given by
$$|\epsilon| = (2.228 \pm 0.011) \times 10^{-3}\,.$$
- Direct CP violation in $K \to \pi\pi$ decays, given by
$$\mathcal{R}e(\epsilon'/\epsilon) = (1.65 \pm 0.26) \times 10^{-3}\,.$$
- Direct CP violation has been established in the difference of asymmetries for $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ decays
$$\Delta a_{CP} = (-0.164 \pm 0.028) \times 10^{-3}.$$
- CP violation in the interference of mixing and decay in the tree-dominated $b \to c\bar{c}s$ transitions, such as $B^0 \to \psi K_S$, given by
$$S_{\psi K^0} = +0.699 \pm 0.017\,.$$
Within the Standard Model, this result can be interpreted with low theoretical uncertainty as measurement of $\sin(2\beta)$, where β is an angle of the unitarity triangle.
- The CP violation parameters in the $B^0 \to \pi^+\pi^-$ mode,
$$S_{\pi^+\pi^-} = -0.63 \pm 0.04\,, \quad C_{\pi^+\pi^-} = -0.32 \pm 0.04\,.$$
Together with measurements of other $B \to \pi\pi$ and similar decays, these results can be used to obtain constraints on the angle α of the unitarity triangle.
- Direct CP violation in $B^+ \to DK^+$ decays, where D_+ and $D_{K^-\pi^+}$ represent that the D meson is reconstructed in a CP-even and the suppressed $K^-\pi^+$ final state respectively,
$$\mathcal{A}_{B^+\to D_+K^+} = +0.129 \pm 0.012\,, \quad \mathcal{A}_{B^+\to D_{K^-\pi^+}K^+} = -0.41 \pm 0.06\,.$$
Together with measurements of other $B \to DK$ and similar decays, these results can be used to obtain constraints on the angle γ of the unitarity triangle.

14. Neutrino Masses, Mixing, and Oscillations

Revised August 2019 by M.C. Gonzalez-Garcia (YITP, Stony Brook; ICREA, Barcelona; ICC, U. of Barcelona) and M. Yokoyama (Tokyo U.; Kavli IPMU (WPI), U. Tokyo).

The weak neutrino eigenstates $|\nu_\alpha\rangle$, i. e. the states produced in the weak CC interaction by the charged leptons ℓ_α ($\alpha = 1, 2, 3$), are linear combination of the mass eigenstates $|\nu_i\rangle$ ($i = 1, 2, 3$) (eigenvalues m_i)

$$|\nu_\alpha\rangle = \sum_{i=1}^{n} U^*_{\alpha i}|\nu_i\rangle \,, \tag{14.35}$$

where U is the mixing matrix. U, assumed to be unitary, can be expressed in terms of three mixing angles, taken by convention $0 \leq \theta_{ij} \leq \pi/2$, and phases $\in (0, 2\pi)$. Experimentally, two masses are close to one another, while the third is more separated. The former ones are defined as ν_1 and ν_2, with the lighter being ν_1. The sign of the larger mass difference defines two possible mass orderings, either "normal" (NO) $m_3 > m_2 > m_1$, or "inverted" (IO) $m_2 > m_1 > m_3$. Experiments show that $|U_{e1}| \geq |U_{e2}| \geq |U_{e3}|$. The mixing matrix is given by

$$U = \begin{pmatrix} c_{12}\, c_{13} & s_{12}\, c_{13} & s_{13}\, e^{-i\delta} \\ -s_{12}\, c_{23} - c_{12}\, s_{13}\, s_{23}\, e^{i\delta} & c_{12}\, c_{23} - s_{12}\, s_{13}\, s_{23}\, e^{i\delta} & c_{13}\, s_{23} \\ s_{12}\, s_{23} - c_{12}\, s_{13}\, c_{23}\, e^{i\delta} & -c_{12}\, s_{23} - s_{12}\, s_{13}\, c_{23}\, e^{i\delta} & c_{13}\, c_{23} \end{pmatrix} \times$$
$$\times\, diag(e^{i\eta_1}, e^{i\eta_2}, 1) \tag{14.33}$$

where $c_{ij} = \cos\theta_{ij}$, $s_{ij} = \sin\theta_{ij}$, $\delta = \delta_{\rm CP}$. The phases η_1 and η_2 are physical if neutrinos are Majorana particles (but irrelevant for oscillations and matter effects), while can be absorbed in the wave functions in the Dirac case. For propagation in vacuum, assuming the state $|\nu_\alpha(t) >$ to be a plane monoenergetic ultra-relativistic wave (namely $p \sim E$), the oscillation probability between two flavours α and β is

$$P_{\alpha\beta} = \delta_{\alpha\beta} - 4\sum_{i<j}^{n} \Re[U_{\alpha i}U^*_{\beta i}U^*_{\alpha j}U_{\beta j}]\sin^2 X_{ij}$$
$$+\,2\sum_{i<j}^{n} \Im[U_{\alpha i}U^*_{\beta i}U^*_{\alpha j}U_{\beta j}]\sin 2X_{ij}\,, \tag{14.39}$$

where

$$X_{ij} = \frac{(m_i^2 - m_j^2)L}{4E} = 1.267\,\frac{\Delta m^2_{ij}}{\text{eV}^2}\,\frac{L/E}{\text{m/MeV}}\,. \tag{14.40}$$

When neutrinos propagate in a dense medium, while absorption is negligible, the effect of coherent interaction with matter, being proportional to G_F, rather than to G_F^2, is not; it affects neutrino phase velocity. In a neutral medium containing nuclei and electrons, the effective potential at point x, with electron density $n_e(x)$, is

$$V = \text{diag}\left(\pm\sqrt{2}G_F\, n_e(x),\, 0,\, 0\right) \tag{14.58}$$

Where the sign + is for neutrinos, − for antineutrinos. In the relevant case of solar neutrinos, ν_e are produced in the core. The propagating system is effectively a two-state one, $\nu_e - \nu_X$ (X is a superposition of ν_μ and ν_τ, which is arbitrary because ν_μ and ν_τ have only NC that are equal). If θ is the mixing angle (in vacuum) and Δm^2 the square mass difference, the instantaneous mixing angle in matter $\theta_m(x)$ is given by

$$\tan 2\theta_m(x) = \frac{\Delta m^2 \sin 2\theta}{\Delta m^2 \cos 2\theta - 2EG_F n_e(x)} . \tag{14.61}$$

Depending on neutrino energy and mixing angle in vacuum, the denominator can cross zero at a certain x. This "resonance" condition may result in an adiabatic flavour conversion in matter (Mikheev-Smirnov-Wolfenstein Effect). The mixing parameters are obtained from global fits to the neutrino data, relative to both phenomena. Fits are performed by three different groups (NUFIT, BARI and VALENCIA), separately for NO and IO. The following is a summary of Table 14.7 of the main review (NUFIT without the SuperKamiokande analysis of matter effects in atmospheric neutrinos)

Table 14.7: Global fit results

Parameter	NUFIT w/o SK-at	BARI	VALENCIA
NO			
$\sin^2\theta_{12}/10{-}1$	$3.10^{+0.13}_{-0.12}$	$3.04^{+0.14}_{-0.13}$	$3.20^{+0.20}_{-0.16}$
$\sin^2\theta_{23}/10^{-1}$	$5.58^{+0.20}_{-0.33}$	$5.51^{+0.19}_{-0.80}$	$5.47^{+0.20}_{-0.30}$
$\sin^2\theta_{13}/10^{-2}$	$2.241^{+0.066}_{-0.065}$	$2.14^{+0.09}_{-0.07}$	$2.160^{+0.063}_{-0.066}$
$\delta_{CP}/°$	222^{+38}_{-28}	238^{+41}_{-33}	218^{+38}_{-27}
$\Delta m^2_{21}/\text{meV}^2$	$73.9^{+2.1}_{-2.0}$	$73.4^{+1.7}_{-1.4}$	$75.5^{+2.0}_{-1.6}$
$\Delta m^2_{32}/\text{meV}^2$	2449^{+32}_{-30}	2419^{+35}_{-32}	2424^{+30}_{-30}
IO	$\Delta\chi^2 = 6.2$	$\Delta\chi^2 = 9.5$	$\Delta\chi^2 = 11.7$
$\sin^2\theta_{12}/10{-}1$	$3.10^{+0.13}_{-0.12}$	$3.03^{+0.14}_{-0.13}$	$3.20^{+0.20}_{-0.16}$
$\sin^2\theta_{23}/10^{-1}$	$5.63^{+0.19}_{-0.26}$	$5.57^{+0.17}_{-0.24}$	$5.51^{+0.18}_{-0.30}$
$\sin^2\theta_{13}/10^{-2}$	$2.261^{+0.067}_{-0.064}$	$2.18^{+0.08}_{-0.07}$	$2.220^{+0.074}_{-0.076}$
$\delta_{CP}/°$	285^{+24}_{-26}	247^{+26}_{-27}	281^{+23}_{-27}
$\Delta m^2_{21}/\text{meV}^2$	$73.9^{+2.1}_{-2.0}$	$73.4^{+1.7}_{-1.4}$	$75.5^{+2.0}_{-1.6}$
$\Delta m^2_{32}/\text{meV}^2$	-2509^{+32}_{-32}	-2478^{+35}_{-33}	-2500^{+40}_{-30}

Fig. 14.9 shows the allowed regions of the NUFIT analysis in terms, as an example, of one of the six leptonic unitary triangles (taking U as unitary by definition)

Information on the absolute scale of neutrino masses comes from three different sources.

1 Cosmology provides indirect limits on the sum of neutrino masses $\sum_{i=1}^{3} m_i$ (see Sec. 25. Neutrinos in cosmology).

2 Measurements, with sub-eV energy resolution, of the end-point of the electron energy spectrum in the decay $^3\text{H} \to {}^3\text{He} + e^- + \bar{\nu}_e$ gives direct information on $(m^{eff}_{\nu_e})^2 = \sum_{i=1}^{3} m_i^2 |U_{ei}|^2$. First result released by the KATRIN experiment provide $m^{eff}_{\nu_e} < 1.1\,\text{eV}$ at 90% CL.

3 Neutrino-less double beta decay $(A, Z) \to (A, Z+2) + 2e^-$ is forbidden in the SM as it violates lepton number conservation (by

2 units). However, if neutrino is a Majorana particle measurements of the half-lives $T^{0\nu}_{1/2}$ of different isotopes give information on $m_{ee} = |\sum_{i=1}^{3} m_i U_{ei}^2|$. The sensitivity reached by experiments on ^{136}Xe and ^{76}Ge ($T^{0\nu}_{1/2} \sim 10^{26}$yr) give bounds of $m_{ee} < 61 - 165$ meV.

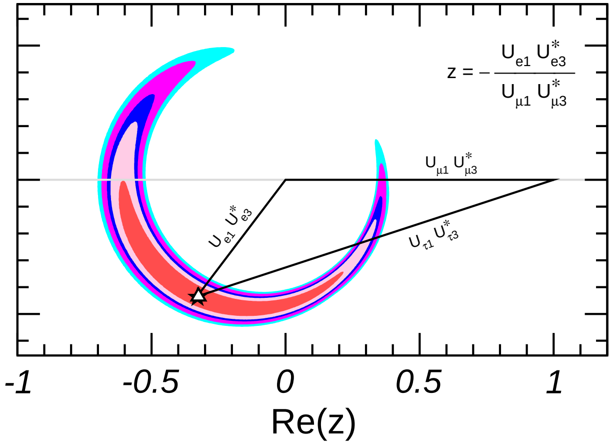


Figure 14.9: Leptonic unitarity triangle for the first and third columns of the mixing matrix. After scaling and rotating the triangle so that two of its vertices always coincide with $(0, 0)$ and $(1, 0)$ the figure shows the 1σ, 90%, 2σ, 99%, 3σ CL (2 dof) allowed regions of the third vertex for the NO from the analysis in Ref. [187, 188].

15. Quark Model

Revised August 2019 by C. Amsler (Stefan Meyer Inst.), T. DeGrand (Colorado U., Boulder) and B. Krusche (Basel U.).

The quarks are strongly interaction spin-1/2 fermions, whose parity is positive by convention. The charges of the u , c, and t quarks are $+2/3$, while those of the d, s, and b are $-1/3$. Their anti-quarks have the opposite charges and parities. By convention, the s quark is said to have negative strangeness and the c quark positive charm. The two lightest quarks, u and d, obey to a high degree an SU(2) symmetry called isospin, with u having $I_z = 1/2$ and d having $I_z = -1/2$. The other quarks can be assigned zero isospin.

Quarks have baryon number $\mathcal{B} = 1/3$, while anti-quarks have $\mathcal{B} = -1/3$. The mesons, which are pairs of quarks and anti-quarks, have $\mathcal{B} = 0$ and can be characterized by their intrinsic spin s, orbital angular momentum ℓ, and total spin J, lying between $|\ell - s|$ and $\ell + s$. The charge conjugation,or C, of meson is $(-1)^{\ell+s}$ while its parity is $(-1)^{\ell+1}$. G-parity combines the charge-conjugation and isospin symmetries: $G = Ce^{-i\pi I_y}$. Mesons made of a quark and its antiquark are G-parity eigenstates with $G = (-1)^{I+\ell+s}$.

The three lightest quarks, u, d, and s, respect an approximate symmetry, flavor SU(3), with quarks belonging to the **3** representation and anti-quarks to the $\overline{\mathbf{3}}$ representation. The quark-anti-quark states made from u, d, and s can be classified according to

$$\mathbf{3} \otimes \overline{\mathbf{3}} = \mathbf{8} \oplus \mathbf{1}. \tag{15.3}$$

A fourth quark such as charm c can be included by extending SU(3) to SU(4). However, SU(4) is badly broken owing to the much heavier c quark. Nevertheless, in an SU(4) classification, the sixteen mesons are grouped into a 15-plet and a singlet:

$$\mathbf{4} \otimes \overline{\mathbf{4}} = \mathbf{15} \oplus \mathbf{1}. \tag{15.4}$$

Baryons are made of three quarks (aside from a five-quark state recently observed at the LHC), allowing for more complex possibilities. The flavor SU(3) content of baryons made of u, d, and s is governed by

$$\mathbf{3} \otimes \mathbf{3} \otimes \mathbf{3} = \mathbf{10} \oplus \mathbf{8} \oplus \mathbf{8} \oplus \mathbf{1}. \tag{15.29}$$

The intrinsic spin of the three quarks yields either $s = 1/2$ or $s = 3/2$. The proton and neutron are members of an octet, while the spin-3/2 Δ^{++} is a member of a decuplet.

The strong interactions are described by the color SU(3) gauge theory, with each quark coming in three "colors." The color triplets interact through a color octet of gluons, gauge vector bosons. These are responsible for the formation of the bound states, mesons and baryons.

22. Big-Bang Cosmology

Revised August 2019 by K.A. Olive (Minnesota U.) and J.A. Peacock (Edinburgh U.).

22.1.1 *The Robertson-Walker Universe*

The observed homogeneity and isotropy enable us to write the most general expression for a space-time metric which has a (3D) maximally symmetric subspace of a 4D space-time, known as the Robertson-Walker metric:

$$ds^2 = dt^2 - R^2(t)\left[\frac{dr^2}{1-kr^2} + r^2\left(d\theta^2 + \sin^2\theta\, d\phi^2\right)\right]. \qquad (22.1)$$

Note that we adopt $c = 1$ throughout. By rescaling the radial coordinate, we can choose the curvature constant k to take only the discrete values $+1$, -1, or 0 corresponding to closed, open, or spatially flat geometries.

22.1.3 *The Friedmann equations of motion*

The cosmological equations of motion are derived from Einstein's equations

$$\mathcal{R}_{\mu\nu} - \tfrac{1}{2}g_{\mu\nu}\mathcal{R} = 8\pi G_{\rm N}T_{\mu\nu} + \Lambda g_{\mu\nu} \qquad (22.6)$$

It is common to assume that the matter content of the Universe is a perfect fluid, for which

$$T_{\mu\nu} = -pg_{\mu\nu} + (p+\rho)\,u_\mu u_\nu, \qquad (22.7)$$

where $g_{\mu\nu}$ is the space-time metric described by Eq. (22.1), p is the isotropic pressure, ρ is the energy density and $u = (1,0,0,0)$ is the velocity vector for the isotropic fluid in co-moving coordinates. With the perfect fluid source, Einstein's equations lead to the Friedmann equations

$$H^2 \equiv \left(\frac{\dot{R}}{R}\right)^2 = \frac{8\pi\ G_{\rm N}\ \rho}{3} - \frac{k}{R^2} + \frac{\Lambda}{3}, \qquad (22.8)$$

and

$$\frac{\ddot{R}}{R} = \frac{\Lambda}{3} - \frac{4\pi G_{\rm N}}{3}\ (\rho + 3p), \qquad (22.9)$$

where $H(t)$ is the Hubble parameter and Λ is the cosmological constant. The first of these is sometimes called the Friedmann equation. Energy conservation via $T^{\mu\nu}_{\ \ ;\mu} = 0$, leads to a third useful equation

$$\dot{\rho} = -3H\,(\rho + p)\,. \qquad (22.10)$$

Eq. (22.10) can also be simply derived as a consequence of the first law of thermodynamics.

22.1.5 *Standard Model solutions*

22.1.5.1 *Solutions for a general equation of state*

Let us first assume a general equation of state parameter for a single component, $w = p/\rho$ which is constant. In this case, Eq. (22.10) can be written as $\dot{\rho} = -3(1+w)\rho\dot{R}/R$ and is easily integrated to yield

$$\rho \propto R^{-3(1+w)}. \qquad (22.16)$$

Curvature domination occurs at rather late times (if a cosmological constant term does not dominate sooner). For $w \neq -1$,

$$R(t) \propto t^{2/[3(1+w)]}. \qquad (22.17)$$

22.1.5.2 *A Radiation-dominated Universe*

In the early hot and dense Universe, it is appropriate to assume an equation of state corresponding to a gas of radiation (or relativistic particles) for which $w = 1/3$. In this case, Eq. (22.16) becomes $\rho \propto R^{-4}$. Similarly, one can substitute $w = 1/3$ into Eq. (22.17) to obtain

$$R(t) \propto t^{1/2}; \qquad H = 1/2t. \tag{22.18}$$

22.1.5.3 *A Matter-dominated Universe*

Non-relativistic matter eventually dominates the energy density over radiation. A pressureless gas ($w = 0$) leads to the expected dependence $\rho \propto R^{-3}$, and, if $k = 0$, we obtain

$$R(t) \propto t^{2/3}; \qquad H = 2/3t. \tag{22.19}$$

22.1.5.4 *A Universe dominated by vacuum energy*

If there is a dominant source of vacuum energy, acting as a cosmological constant with equation of state $w = -1$. This leads to an exponential expansion of the Universe:

$$R(t) \propto e^{\sqrt{\Lambda/3}\,t}. \tag{22.20}$$

22.3 The Hot Thermal Universe

22.3.2 *Radiation content of the Early Universe*

At the very high temperatures associated with the early Universe, massive particles are pair produced, and are part of the thermal bath. If for a given particle species i we have $T \gg m_i$, then we can neglect the mass and the thermodynamic quantities are easily computed. In general, we can approximate the energy density (at high temperatures) by including only those particles with $m_i \ll T$. In this case, we have

$$\rho = \left(\sum_{\mathrm{B}} g_{\mathrm{B}} + \frac{7}{8} \sum_{\mathrm{F}} g_{\mathrm{F}} \right) \frac{\pi^2}{30} T^4 \equiv \frac{\pi^2}{30}\, N(T)\, T^4, \tag{22.42}$$

where $g_{\mathrm{B(F)}}$ is the number of degrees of freedom of each boson (fermion) and the sum runs over all boson and fermion states with $m \ll T$. Eq. (22.42) defines the effective number of degrees of freedom, $N(T)$, by taking into account new particle degrees of freedom as the temperature is raised.

The value of $N(T)$ at any given temperature depends on the particle physics model. In the standard $\mathrm{SU}(3) \times \mathrm{SU}(2) \times \mathrm{U}(1)$ model, we can specify $N(T)$ up to temperatures of $O(100)$ GeV. At higher temperatures, $N(T)$ will be model-dependent.

In the radiation-dominated epoch, Eq. (22.10) can be integrated (neglecting the T-dependence of N) giving us a relationship between the age of the Universe and its temperature

$$t = \left(\frac{90}{32\pi^3 G_{\mathrm{N}} N(T)} \right)^{1/2} T^{-2}\ . \tag{22.43}$$

Put into a more convenient form

$$t\, T_{\mathrm{MeV}}^2 = 2.4[N(T)]^{-1/2}, \tag{22.44}$$

where t is measured in seconds and T_{MeV} in units of MeV.

27. Dark Matter

Revised August 2019 by L. Baudis (Zurich U.) and S. Profumo (UC Santa Cruz).

27.6 Laboratory detection of dark matter

Laboratory searches for DM particles can be roughly classified in direct detection experiments, axion searches, and searches at accelerators and colliders.

27.6.1 *Searches at Accelerators and Colliders*

Various searches for dark matter have been carried out by the CMS and ATLAS collaborations at the LHC in *pp* collisions [99–103]. In general, these assume that dark matter particles escape the detector without interacting leading to significant amounts of missing energy and momentum.

27.6.2 *Direct detection formalism*

Direct detection experiments mostly aim to observe elastic or inelastic scatters of Galactic DM particles with atomic nuclei, or with electrons in the detector material. Predicted event rates assume a certain mass and scattering cross section, as well as a set of astrophysical parameters: the local density ρ_0, the velocity distribution $f(\vec{v})$, and the escape velocity v_{esc} (see Sec. 27.4).

Figure 27.1 shows the best constraints for SI couplings in the cross section versus DM mass parameter space, above masses of 0.3 GeV.

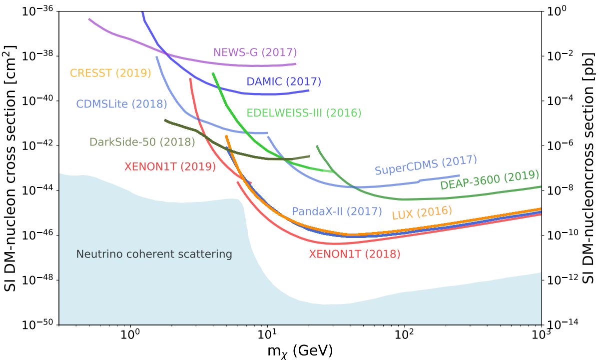


Figure 27.1: Upper limits on the SI DM-nucleon cross section as a function of DM mass.

27.7 Astrophysical detection of dark matter

DM as a microscopic constituent can have measurable, macroscopic effects on astrophysical systems. Indirect DM detection refers to the search for the annihilation or decay debris from DM particles, resulting in detectable species, including especially gamma rays, neutrinos, and antimatter particles. The production rate of such particles depends on (i) the annihilation (or decay) rate (ii) the density of pairs (respectively, of individual particles) in the region of interest, and (iii) the number of final-state particles produced in one annihilation (decay) event.

29. Cosmic Microwave Background

Revised August 2019 by D. Scott (U. of British Columbia) and G.F. Smoot (HKUST; Paris U.; UC Berkeley; LBNL).

29.2 CMB Spectrum

It is well known that the spectrum of the microwave background is very precisely that of blackbody radiation, whose temperature evolves with redshift as $T(z) = T_0(1+z)$ in an expanding universe.

29.3 Description of CMB Anisotropies

Observations show that the CMB contains temperature anisotropies at the 10^{-5} level and polarization anisotropies at the 10^{-6} (and lower) level, over a wide range of angular scales. These anisotropies are usually expressed using a spherical harmonic expansion of the CMB sky:

$$T(\theta,\phi) = \sum_{\ell m} a_{\ell m} Y_{\ell m}(\theta,\phi) \tag{29.1}$$

(with the linear polarization pattern written in a similar way using the so-called spin-2 spherical harmonics). Increasing angular resolution requires that the expansion goes to higher multipoles. Because there are only very weak phase correlations seen in the CMB sky and since we notice no preferred direction, the vast majority of the cosmological information is contained in the temperature 2-point function, *i.e.*, the variance as a function only of angular separation. Equivalently, the power per unit $\ln \ell$ is $\ell \sum_m |a_{\ell m}|^2 / 4\pi$.

29.3.1 *The Monopole*

The CMB has a mean temperature of $T_\gamma = 2.7255 \pm 0.0006\,\mathrm{K}$ (1σ) [23], which can be considered as the monopole component of CMB maps, a_{00}. Since all mapping experiments involve difference measurements, they are insensitive to this average level; monopole measurements can only be made with absolute temperature devices, such as the FIRAS instrument on the *COBE* satellite [24]. The measured kT_γ is equivalent to 0.234 meV or $4.60 \times 10^{-10}\, m_{\mathrm{e}}c^2$. A blackbody of the measured temperature has a number density $n_\gamma = (2\zeta(3)/\pi^2)\, T_\gamma^3 \simeq 411\,\mathrm{cm}^{-3}$, energy density $\rho_\gamma = (\pi^2/15)\, T_\gamma^4 \simeq 4.64 \times 10^{-34}\,\mathrm{g\,cm}^{-3} \simeq 0.260\,\mathrm{eV\,cm}^{-3}$, and a fraction of the critical density $\Omega_\gamma \simeq 5.38 \times 10^{-5}$.

29.3.2 *The Dipole*

The largest anisotropy is in the $\ell = 1$ (dipole) first spherical harmonic, with amplitude $3.3621 \pm 0.0010\,\mathrm{mK}$ [13]. The dipole is interpreted to be the result of the Doppler boosting of the monopole caused by the Solar System motion relative to the nearly isotropic blackbody field, as broadly confirmed by measurements of the radial velocities of local galaxies (*e.g.*, Ref. [25]).

29.3.3 *Higher-Order Multipoles*

The variations in the CMB temperature maps at higher multipoles ($\ell \geq 2$) are interpreted as being mostly the result of perturbations in the density of the early Universe, manifesting themselves at the epoch of the last scattering of the CMB photons.

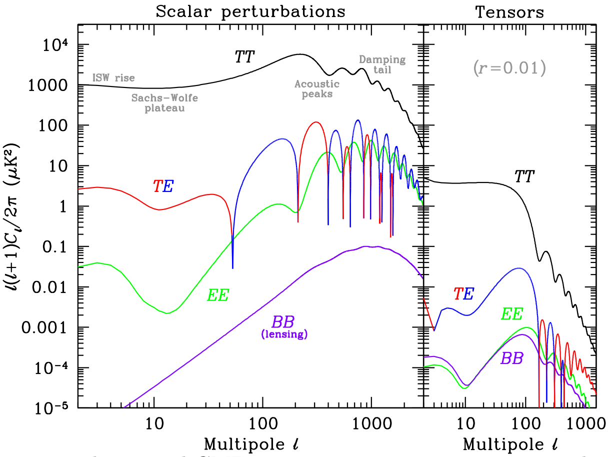


Figure 29.1: Theoretical CMB anisotropy power spectra, using the best-fitting ΛCDM model from *Planck*, calculated using `CAMB`. The panel on the left shows the theoretical expectation for scalar perturbations, while the panel on the right is for tensor perturbations, with an amplitude set to $r = 0.01$ for illustration.

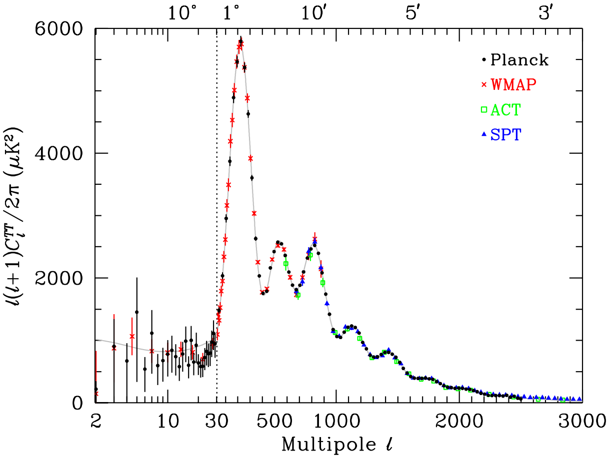


Figure 29.2: CMB temperature anisotropy band-power estimates from the *Planck*, *WMAP*, ACT, and SPT experiments. The acoustic peaks and damping region are very clearly observed, with no need for a theoretical line to guide the eye; however, the curve plotted is the best-fit *Planck* ΛCDM model.

30. Cosmic Rays

Revised October 2019 by J.J. Beatty (Ohio State U.), J. Matthews (Louisiana State U.) and S.P. Wakely (Chicago U.; Chicago U., Kavli Inst.).

Cosmic ray spectra are expressed in terms of differential intensity I with units $[\mathrm{m}^{-2}\,\mathrm{s}^{-1}\mathrm{sr}^{-1}\mathcal{E}^{-1}]$, where the unit for $\mathcal{E}$ is chosen from energy per nucleon, energy per nucleus, and magnetic rigidity depending on the application.

Primary Cosmic Rays

The intensity of primary nucleons in the energy range from several GeV to somewhat beyond 100 TeV is given approximately by

$$I_N(E) \approx 1.8 \times 10^4 (E/1\ \mathrm{GeV})^{-\alpha} \frac{\text{nucleons}}{\mathrm{m}^2\ \mathrm{s\ sr\ GeV}}$$

where E is the energy-per-nucleon (including rest mass energy) and $\alpha = 2.7$ is the differential spectral index. About 74% of the primary nucleons are free protons and about 70% of the rest are bound in helium nuclei. At higher energies, the all-particle spectrum in terms of energy per *nucleus* is used. Above a few times 10^{15} eV the spectrum steepens at the 'knee', again steepens at a 'second knee' near 10^{17} eV, and flattens at the 'ankle' near $10^{18.5}$ eV. Above 5×10^{19} eV the spectrum steepens rapidly due to the onset of inelastic interactions with the cosmic microwave background.

Secondary Cosmic Rays at Sea Level

Cosmic rays at sea level are mostly muons from air showers induced by primary cosmic rays. The integral intensity of vertical muons above 1 GeV/c at sea level is $\approx 70\ \mathrm{m}^{-2}\,\mathrm{s}^{-1}\mathrm{sr}^{-1}$. The overall angular distribution of muons at the ground as a function of zenith angle θ is $\propto \cos^2\theta$. This results in a muon rate of about $1\ \mathrm{cm}^{-2}\,\mathrm{min}^{-1}$ for a thin horizontal detector. In addition to muons, there is a significant component of electrons and positrons with an integral vertical intensity very approximately 30, 6, and 0.2 $\mathrm{m}^{-2}\,\mathrm{s}^{-1}\mathrm{sr}^{-1}$ above 10, 100, and 1000 MeV respectively, with a complicated angular dependence. The integral intensity of vertical protons above 1 GeV/c at sea level is $\approx 0.9\ \mathrm{m}^{-2}\,\mathrm{sr}^{-1}$, accompanied by neutrons at about 1/3 of the proton flux.

Particles in the Atmosphere and Underground

At altitudes h between 1 and 6 km above sea level the vertical flux of particles with $E > 1$ GeV is dominated by muons with a flux of $\approx 100\ \mathrm{m}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1} \times (h/\mathrm{km})^{0.42}$.

The underground charged particle flux is predominantly muons. For ice or water at depth $d > 1$ km the vertical flux is $\approx 2.2 \times 10^{-2}\ \mathrm{m}^{-2}\mathrm{s}^{-1}$ $\mathrm{sr}^{-1} \times (\mathrm{d/km})^{-4.5}$. Below depths of ≈ 20 km w.e., most remaining muons are produced by neutrino interactions. The upward-going vertical intensity of muons above 2 GeV is $\approx 2 \times 10^{-9}\ \mathrm{m}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}$. The horizontal intensity below 20 km w.e. is about twice the upward-going vertical intensity.

For details and references see the full *Review of Particle Physics*.

31. Accelerator Physics of Colliders

Revised August 2019 by M.J. Syphers (Northern Illinois U.; FNAL) and F. Zimmermann (CERN).

The number of events, N_{exp}, is the product of the cross section of interest, σ_{exp}, and the time integral over the instantaneous *luminosity*, $\mathcal{L}$:

$$N_{exp} = \sigma_{exp} \times \int \mathcal{L}(t)dt. \tag{31.1}$$

Today's colliders all employ bunched beams. If two bunches containing n_1 and n_2 particles collide head-on with frequency $f_{\rm coll}$, a basic expression for the luminosity is

$$\mathcal{L} = f_{\rm coll} \frac{n_1 n_2}{4\pi\sigma_x^* \sigma_y^*} \mathcal{F} \tag{31.2}$$

where σ_x^* and σ_y^* characterize the rms transverse beam sizes in the horizontal (bend) and vertical directions at the interaction point, and $\mathcal{F}$ is a factor of order 1, that takes into account geometric effects such as a crossing angle and finite bunch length, and dynamic effects, such as the mutual focusing of the two beam during the collision.

For a beam with a Gaussian distribution in x, x', the area containing one standard deviation σ_x, divided by π, is used as the definition of emittances:

$$\varepsilon_x \equiv \frac{\sigma_x^2}{\beta_x}, \tag{31.11}$$

with a corresponding expression in the other transverse direction, y.

Eq. 31.2 can be recast in terms of emittances and amplitude functions as

$$\mathcal{L} = f \frac{n_1 n_2}{4\pi \sqrt{\varepsilon_x\, \beta_x^*\, \varepsilon_y\, \beta_y^*}}\ \mathcal{F}. \tag{31.12}$$

Here, β^* is the value of the amplitude function at the interaction point.

A bunch in beam 1 presents a (nonlinear) lens to a particle in beam 2 resulting in changes to the particle's transverse tune with a range characterized by the beam-beam parameter

$$\xi_{y,2} = \frac{m_e r_e q_1 q_2 n_1 \beta_{y,2}^*}{2\pi m_{A,2} \gamma_2 \sigma_{y,1}^* (\sigma_{x,1}^* + \sigma_{y,1}^*)} \tag{31.13}$$

where r_e denotes the classical electron radius ($r_e \approx 2.8 \times 10^{-15}$ m), m_e the electron mass, q_1 (q_2) the particle charge of beam 1 (2) in units of the elementary charge, and $m_{A,2}$ the mass of beam-2 particles.

Eq. 31.2 for linear colliders can be written as:

$$\mathcal{L} \approx \frac{137}{8\pi r_e} \frac{P_{\rm wall}}{E_{cm}} \frac{\eta}{\sigma_y^*} N_\gamma H_D\,. \tag{31.14}$$

Here, $P_{\rm wall}$ is the total wall-plug power of the collider, $\eta \equiv P_b/P_{\rm wall}$ the efficiency of converting wall-plug power into beam power $P_b = f_{\rm coll} n E_{cm}$, E_{cm} the cms energy, n ($= n_1 = n_2$) the bunch population, and σ_y^* the vertical rms beam size at the collision point. In formulating Eq. 31.14 the number of beamstrahlung photons emitted per $e^\pm$, was approximated as $N_\gamma \approx 2\alpha r_e n/\sigma_x^*$, where α denotes the fine-structure constant.

Table: Tentative parameters of selected future high-energy colliders. Parameters associated with different beam energy scenarios are comma-separated. Quantities are, where appropriate, r.m.s.; H and V indicate horizontal and vertical directions. See full *Review* for complete tables. Parameters for other proposed high-energy colliders, including a muon collider, can also be found in the full *Review*.

	FCC-ee	CEPC	ILC	LHeC	HE-LHC	FCC-hh
Species	e^+e^-	e^+e^-	e^+e^-	ep	pp	pp
Beam energy (TeV)	0.046, 0.120, 0.183	0.046, 0.120	0.125, 0.25	0.06(e), 7 (p)	13.5	50
Circumference / Length (km)	97.75	100	20.5, 31	9(e), 26.7 (p)	26.7	97.75
Interaction regions	2	2	1	1	2 (4)	4
Luminosity (10^{34}/cm^2/s)	230, 8.5, 1.6	32, 3	1.4, 1.8	0.8	16	5–30
Time between collisions (μs)	0.015, 0.75, 8.5	0.025, 0.68	0.55	0.025	0.025	0.025
Bunch length (rms, mm)	12.1, 5.3, 3.8	8.5, 3.3	0.3	0.06 (e), 75.5(p)	80	80
IP beam size (μm)	H: 6.3, 14, 38 V: 0.03, 0.04, 0.07	H: 5.9, 21, V: 0.04, 0.07	H: 0.52, 0.47, V: 0.008, 0.006	4.3 (round)	8.8	6.6-3.5 (init.)
β^*, amplitude function at interaction point (cm)	H: 15, 30, 100 V: 0.08, 0.1, 0.16	H: 20, 36 V: 0.1, 0.15	H: 1.3, 2.2 V: 0.041, 0.048	5.0(e) 7.0(p)	45	110–30
RF frequency (MHz)	400, 400, 800	650	1300	800(e), 400(p)	400	400
Particles per bunch (10^{10})	17, 15, 27	8, 15	2	0.23(e), 22(p)	22	10
Average beam current (mA)	1390, 29, 5.4	19.2	6 (in train)	15(e), 883(p)	1120	500
SR power loss (MW)	100	64	n/a	30(e), 0.01(p)	0.1	2.4

Table: Updated in March 2020 with numbers received from representatives of the colliders (contact E. Pianori, LBNL). The table shows the parameter values achieved by December 2019.Quantities are, where appropriate, r.m.s.; unless noted otherwise, energies refer to beam energy; H and V indicate horizontal and vertical directions; only selected colliders operating in 2018-2019 are included. See full *Review* for complete tables.

	VEPP-2000 (Novosibirsk)	VEPP-4M (Novosibirsk)	BEPC-II (China)	SuperKEKB (KEK)	LHC (CERN)
Physics start date	2010	1994	2008	2018	2009
Particles collided	e^+e^-	e^+e^-	e^+e^-	e^+e^-	pp
Maximum beam energy (GeV)	1.0	6	1.89 (2.35 max)	e^-: 7, e^+: 4	6500
Luminosity (10^{30} cm^{-2}s^{-1})	50	20	1000	1.88×10^4	2.1×10^4
Time between collisions (ns)	40	600	8	6.5	24.95
Energy spread (units 10^{-3})	0.71	1	0.52	e^-/e^+: 0.64/0.81	0.105
Bunch length (cm)	4	5	≈ 1.2	e^-/e^+: 0.5/0.6	8
Beam radius (10^{-6} m)	125 (round)	H:1000 V:30	H:347 V:4.5	e^-: 16.6 (H), 0.25 (V) e^+: 12.6 (H), 0.25 (V)	8.5
Free space at interaction point (m)	±0.5	±2	±0.63	$e^-: +1.20/-1.28, e^+: +0.78/-0.73$ (+300/−500) mrad cone	38
β^*, amplitude function at interaction point (m)	H:0.05 - 0.11 V:0.05 - 0.11	H:0.75 V:0.05	H:1.0 V:0.0129	e^-: 0.060 (H), 1×10^{-3} (V) e^+: 0.080 (H), 1×10^{-3} (V)	$0.3 \rightarrow 0.29$
Interaction regions	2	1	1	1	4 total, 2 high $\mathfrak{L}$

34. Passage of Particles Through Matter

Revised August 2019 by D.E. Groom (LBNL) and S.R. Klein (NSD LBLN).

This review covers the interactions of photons and electrically charged particles in matter, concentrating on energies of interest for high-energy physics and astrophysics and processes of interest for particle detectors.

Table 34.1: Summary of variables used in this section. The kinematic variables β and γ have their usual relativistic meanings.

Symb.	Definition	Value or (usual) units
$m_e c^2$	electron mass $\times\ c^2$	$0.510\,998\,950\,00(15)$ MeV
r_e	classical electron radius $e^2/4\pi\epsilon_0 m_e c^2$	$2.817\,940\,3262(13)$ fm
α	fine structure constant $e^2/4\pi\epsilon_0\hbar c$	$1/137.035\,999\,084(21)$
N_A	Avogadro's number	$6.022\,140\,76\times 10^{23}$ mol^{-1}
ρ	density	g cm^{-3}
x	mass per unit area	g cm^{-2}
M	incident particle mass	MeV/c^2
E	incident part. energy γMc^2	MeV
T	kinetic energy, $(\gamma-1)Mc^2$	MeV
W	energy transfer to an electron in a single collision	MeV
k	bremsstrahlung photon energy	MeV
z	charge number of incident particle	
Z	atomic number of absorber	
A	atomic mass of absorber	g mol^{-1}
K	$4\pi N_A r_e^2 m_e c^2$ (Coefficient for dE/dx)	0.307 075 MeV mol^{-1} cm^2
I	mean excitation energy	eV (*Nota bene!*)
$\delta(\beta\gamma)$	density effect correction to ionization energy loss	
$\hbar\omega_p$	plasma energy $\sqrt{4\pi N_e r_e^3}\ m_e c^2/\alpha$	$\sqrt{\rho\,\langle Z/A\rangle}\times 28.816$ eV ↳ ρ in g cm^{-3}
N_e	electron density	(units of r_e)$^{-3}$
w_j	weight fraction of the jth element in a compound or mixt.	
n_j	$\propto$ number of jth kind of atoms in a compound or mixture	
X_0	radiation length	g cm^{-2}
E_c	critical energy for electrons	MeV
$E_{\mu c}$	critical energy for muons	GeV
E_s	scale energy $\sqrt{4\pi/\alpha}\ m_e c^2$	21.2052 MeV
R_M	Molière radius	g cm^{-2}

34.2.2 *Maximum energy transfer in a single collision*

For a particle with mass M,

$$W_{\max} = \frac{2m_e c^2\,\beta^2\gamma^2}{1+2\gamma m_e/M + (m_e/M)^2}\ . \tag{34.4}$$

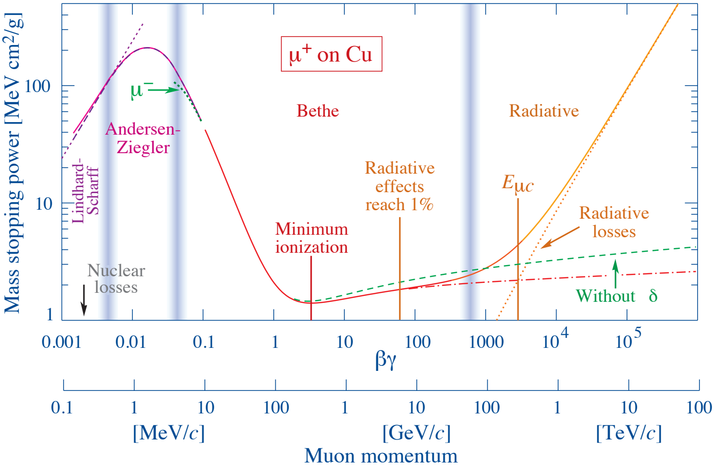


Figure 34.1: Mass stopping power ($= \langle -dE/dx \rangle$) for positive muons in copper as a function of $\beta\gamma = p/Mc$ over nine orders of magnitude in momentum (12 orders of magnitude in kinetic energy). Vertical bands indicate boundaries between different approximations discussed in the text.

34.2.3 *Stopping power at intermediate energies*

The mean rate of energy loss by moderately relativistic charged heavy particles is well-described by the "Bethe equation,"

$$\left\langle -\frac{dE}{dx} \right\rangle = K z^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2 m_e c^2 \beta^2 \gamma^2 W_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right] . \quad (34.5)$$

This is the *mass stopping power*; with the symbol definitions and values given in Table 34.1, the units are MeV g^{-1}cm^2. As can be seen from Fig. 34.2, $\langle -dE/dx \rangle$ defined in this way is about the same for most materials, decreasing slowly with Z. The *linear stopping power*, in MeV/cm, is $\langle -dE/dx \rangle \, \rho$, where ρ is the density in g/cm^3.

As the particle energy increases, its electric field flattens and extends, so that the distant-collision contribution to Eq. (34.5) increases as $\ln \beta\gamma$. However, real media become polarized, limiting the field extension and effectively truncating this part of the logarithmic rise. Parameterization of the density effect term $\delta(\beta\gamma)$ in Eq. (34.5) is discussed in the full *Review* .

Few concepts in high-energy physics are as misused as $\langle dE/dx \rangle$. The mean is weighted by very rare events with large single-collision energy deposits. Even with samples of hundreds of events a dependable value for the mean energy loss cannot be obtained. Far better and more easily measured is the most probable energy loss, discussed below.

Although it must be used with cautions and caveats, $\langle dE/dx \rangle$ as described in Eq. (34.5) still forms the basis of much of our understanding of energy loss by charged particles. Extensive tables are available [`pdg.lbl.gov/AtomicNuclearProperties/`].

Eq. (34.5) may be integrated to find the total (or partial) "continuous slowing-down approximation" (CSDA) range R. Since dE/dx depends (nearly) only on β, R/M is a function of E/M or pc/M.

34.2.9 *Fluctuations in energy loss*

For detectors of moderate thickness x (*e.g.* scintillators or LAr cells), the energy loss probability distribution $f(\Delta;\beta\gamma,x)$ is adequately described by the highly-skewed Landau (or Landau-Vavilov) distribution [29] [28]. The most probable energy loss

$$\Delta_p = \xi\left[\ln\frac{2mc^2\beta^2\gamma^2}{I} + \ln\frac{\xi}{I} + j - \beta^2 - \delta(\beta\gamma)\right] , \qquad (34.12)$$

where $\xi = (K/2)\,\langle Z/A\rangle\, z^2(x/\beta^2)$ MeV for a detector with a thickness x in g cm^{-2}, and $j = 0.200$ [30].While dE/dx is independent of thickness, Δ_p/x scales as $a\ln x{+}b$. This most probable energy loss reaches a (Fermi) plateau rather than continuing $\langle dE/dx\rangle$'s lograthmic rise with increasing energy.

34.4 Photon and electron interactions in matter

At low energies electrons and positrons primarily lose energy by ionization, although other processes (Møller scattering, Bhabha scattering, e^+ annihilation) contribute. While ionization loss rates rise logarithmically with energy, bremsstrahlung losses rise nearly linearly (fractional loss is nearly independent of energy), and dominates above the critical energy (Sec. 34.4.4 below), a few tens of MeV in most materials.

34.4.1 *Collision energy losses by* $e^\pm$

Stopping power differs somewhat for electrons and positrons, and both differ from stopping power for heavy particles because of the kinematics, spin, charge, and the identity of the incident electron with the electrons that it ionizes. Complete discussions and tables can be found in Refs. [10, 13], and [33] in the full *Review.*

34.4.2 *Radiation length*

High-energy electrons predominantly lose energy in matter by bremsstrahlung, and high-energy photons by e^+e^- pair production. The characteristic amount of matter traversed for these related interactions is called the radiation length X_0, usually measured in g cm^{-2}. X_0 has been calculated and tabulated by Y.S. Tsai [42]:

$$\frac{1}{X_0} = 4\alpha r_e^2\frac{N_A}{A}\left\{Z^2\Big[L_{\rm rad} - f(Z)\Big] + Z\,L'_{\rm rad}\right\} . \qquad (34.25)$$

For $A = 1$ g mol^{-1}, $4\alpha r_e^2 N_A/A = (716.408\ \text{g cm}^{-2})^{-1}$. $L_{\rm rad}$ and $L'_{\rm rad}$ are tabulated in the full *Review*, where a 4-place approximation for $f(z)$ is also given.

34.4.3 *Bremsstrahlung energy loss by* $e^\pm$

At very high energies and except at the high-energy tip of the bremsstrahlung spectrum, the cross section can be approximated in the "complete screening case" as [42]

$$d\sigma/dk = (1/k)4\alpha r_e^2\Big\{(\tfrac{4}{3} - \tfrac{4}{3}y + y^2)[Z^2(L_{\rm rad} - f(Z)) + Z\,L'_{\rm rad}] + \tfrac{1}{9}(1-y)(Z^2+Z)\Big\} , \qquad (34.28)$$

where $y = k/E$ is the fraction of the electron's energy transferred to the radiated photon. At small y (the "infrared limit") the term on the second line ranges from 1.7% (low Z) to 2.5% (high Z) of the total. If it is ignored and the first line simplified with the definition of X_0 given in Eq. (34.25), we have

$$\frac{d\sigma}{dk} = \frac{A}{X_0 N_A k} \left(\tfrac{4}{3} - \tfrac{4}{3}y + y^2 \right) . \tag{34.29}$$

34.4.4 *Critical energy*

An electron loses energy by bremsstrahlung at a rate nearly proportional to its energy, while the ionization loss rate varies only logarithmically with the electron energy. The *critical energy* E_c is sometimes defined as the energy at which the two loss rates are equal [49]. Among alternate definitions is that of Rossi [2], who defines the critical energy as the energy at which the ionization loss per radiation length is equal to the electron energy. Equivalently, it is the same as the first definition with the approximation $|dE/dx|_{\rm brems} \approx E/X_0$. This form has been found to describe transverse electromagnetic shower development more accurately.

Values of E_c for electrons can be reasonaby well described by (610 MeV) /($Z + 1.24$) for solids and (710 MeV)/($Z + 0.92$) for gases. E_c for both electrons and positrons in more than 350 materials can be found at `pdg.lbl.gov/AtomicNuclearProperties`.

34.4.5 *Energy loss by photons*

At low energies the photoelectric effect dominates, although Compton scattering, Rayleigh scattering, and photonuclear absorption also contribute. The photoelectric cross section is characterized by discontinuities (absorption edges) as thresholds for photoionization of various atomic levels are reached. Pair production dominates at high energies, but is supressed at ultrahigh energies because of quantum mechanical interference between amplitudes from different scattering centers (LPM effect).

At still higher photon and electron energies, where the bremsstrahlung and pair production cross-sections are heavily suppressed by the LPM effect, photonuclear and electronuclear interactions predominate over electromagnetic interactions. At photon energies above about 10^{20} eV, for example, photons usually interact hadronically.

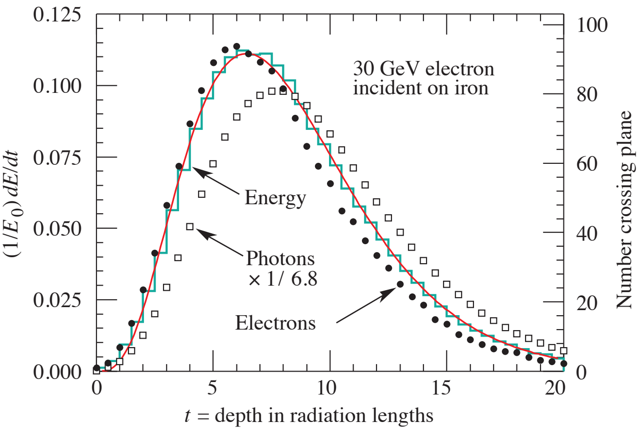


Figure 34.20: An EGS4 simulation of a 30 GeV electron-induced cascade in iron. The histogram shows fractional energy deposition per radiation length, and the curve is a gamma-function fit to the distribution.

34.5 Electromagnetic cascades

When a high-energy electron or photon is incident on a thick absorber, it initiates an electromagnetic cascade as pair production and bremsstrahlung generate more electrons and photons with lower energies.

The longitudinal development is governed by the high-energy part of the cascade, and therefore scales as the radiation length in the material. Electron energies eventually fall below the critical energy, and then dissipate their energy by ionization and excitation rather than by the generation of more shower particles. In describing shower behavior, it is convenient to introduce the scale variables

$$t = x/X_0, \qquad y = E/E_c, \tag{34.34}$$

so that distance is measured in units of radiation length and energy in units of critical energy.

The mean longitudinal profile of the energy deposition in an electromagnetic cascade is reasonably well described by a gamma distribution [61]:

$$\frac{dE}{dt} = E_0\, b\, \frac{(bt)^{a-1} e^{-bt}}{\Gamma(a)} \tag{34.35}$$

at energies from 1 GeV to 100 GeV.

34.6 Muon energy loss at high energy

At sufficiently high energies, radiative processes become more important than ionization for all charged particles. These contributions increase almost linearily with energy. It is convenient to write the average rate of muon energy loss as [74]

$$-dE/dx = a(E) + b(E)\, E. \tag{34.39}$$

Here $a(E)$ is the ionization energy loss given by Eq. (34.5), and $b(E)\, E$ is the sum of e^+e^- pair production, bremsstrahlung, and photonuclear contributions. These are subject large fluctuations, particularly at higher energies.

To the approximation that the slowly-varying functions $a(E)$ and $b(E)$ are constant, the mean range x_0 of a muon with initial energy E_0 is given by

$$x_0 \approx (1/b) \ln(1 + E_0/E_{\mu c}), \tag{34.40}$$

where $E_{\mu c} = a/b$.

The "muon critical energy" $E_{\mu c}$ can be defined as the energy at which radiative and ionization losses are equal, and can be found by solving $E_{\mu c} = a(E_{\mu c})/b(E_{\mu c})$. This definition is different from the Rossi definition we used for electrons. It decreases with Z, and is several hundred GeV for iron. It is given for the elements and many other materials in `pdg.lbl.gov/AtomicNuclearProperties`.

34.7 Cherenkov and transition radiation

A charged particle radiates if its velocity is greater than the local phase velocity of light (Cherenkov radiation) or if it crosses suddenly from one medium to another with different optical properties (transition radiation). Neither process is important for energy loss, but both are used in high-energy and cosmic-ray physics detectors.

34.7.1 *Optical Cherenkov radiation*

The angle θ_c of Cherenkov radiation, relative to the particle's direction, for a particle with velocity βc in a medium with index of refraction n is

$$\begin{aligned} \cos\theta_c &= (1/n\beta) \\ \text{or} \quad \tan\theta_c &= \sqrt{\beta^2 n^2 - 1} \\ &\approx \sqrt{2(1-1/n\beta)} \quad \text{for small } \theta_c, \textit{e.g.} \text{ in gases.} \end{aligned} \tag{34.41}$$

The threshold velocity β_t is $1/n$. Values of $n-1$ for various commonly used gases are given as a function of pressure and wavelength in Ref. [80]. Data for other commonly used materials are given in [81].

The number of photons produced per unit path length of a particle with charge ze and per unit energy interval of the photons is

$$\begin{aligned} \frac{d^2N}{dEdx} &= \frac{\alpha z^2}{\hbar c}\sin^2\theta_c = \frac{\alpha^2 z^2}{r_e\, m_e c^2}\left(1 - \frac{1}{\beta^2 n^2(E)}\right) \\ &\approx 370 \sin^2\theta_c(E) \text{ eV}^{-1}\text{cm}^{-1} \qquad (z=1)\ , \end{aligned} \tag{34.43}$$

or, equivalently,

$$\frac{d^2N}{dxd\lambda} = \frac{2\pi\alpha z^2}{\lambda^2}\left(1 - \frac{1}{\beta^2 n^2(\lambda)}\right)\ . \tag{34.44}$$

34.7.2 *Coherent radio Cherenkov radiation*

Coherent Cherenkov radiation is produced by many charged particles with a non-zero net charge moving through matter on an approximately common "wavefront"—for example, the electrons and positrons in a high-energy electromagnetic cascade. Near the end of a shower, when typical particle energies are below E_c (but still relativistic), a charge imbalance develops. Photons can Compton-scatter atomic electrons, and positrons can annihilate with atomic electrons to contribute even more photons which can in turn Compton scatter. These processes result in a roughly 20% excess of electrons over positrons in a shower. The net negative charge leads to coherent radio Cherenkov emission. The phenomenon is called the Askaryan effect [86]. The signals can be visible above backgrounds for shower energies as low as 10^{17} eV; see Sec. 36.3.3.3 for more details.

34.7.3 *Transition radiation*

The energy radiated when a particle with charge ze crosses the boundary between vacuum and a medium with plasma frequency ω_p is

$$I = \alpha z^2 \gamma \hbar\omega_p/3, \tag{34.45}$$

The plasma energy $\hbar\omega_p$ is defined in Table 34.1.

For styrene and similar materials, $\hbar\omega_p \approx 20$ eV; for air it is 0.7 eV. The number spectrum $dN_\gamma/d(\hbar\omega$ diverges logarithmically at low energies and decreases rapidly for $\hbar\omega/\gamma\hbar\omega_p > 1$. Inevitable absorption in a practical detector removes the divergence. About half the energy is emitted in the range $0.1 \le \hbar\omega/\gamma\hbar\omega_p \le 1$. The γ dependence of the emitted energy thus comes from the hardening of the spectrum rather than from an increased quantum yield. For a particle with $\gamma = 10^3$, the radiated photons are in the soft x-ray range 2 to 40 keV.

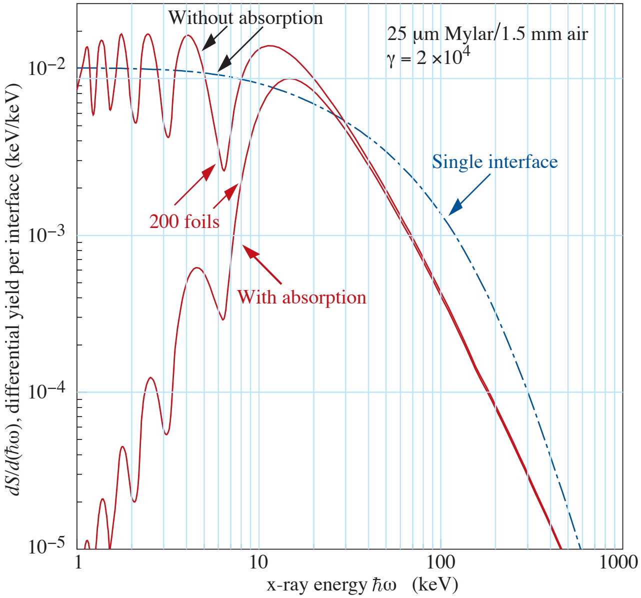


Figure 34.27: X-ray photon energy spectra for a radiator consisting of 200 25 μm thick foils of Mylar with 1.5 mm spacing in air (solid lines) and for a single surface (dashed line).

The number of photons with energy $\hbar\omega > \hbar\omega_0$ is given by the answer to problem 13.15 in [35],

$$N_\gamma(\hbar\omega > \hbar\omega_0) = \frac{\alpha z^2}{\pi}\left[\left(\ln\frac{\gamma\hbar\omega_p}{\hbar\omega_0} - 1\right)^2 + \frac{\pi^2}{12}\right], \tag{34.47}$$

within corrections of order $(\hbar\omega_0/\gamma\hbar\omega_p)^2$. The number of photons above a fixed energy $\hbar\omega_0 \ll \gamma\hbar\omega_p$ thus grows as $(\ln\gamma)^2$, but the number above a fixed fraction of $\gamma\hbar\omega_p$ (as in the example above) is constant. For example, for $\hbar\omega > \gamma\hbar\omega_p/10$, $N_\gamma = 2.519\,\alpha z^2/\pi = 0.0059 \times z^2$.

The particle stays "in phase" with the x ray over a distance called the formation length, $d(\omega) = (2c/\omega)(1/\gamma^2 + \theta^2 + \omega_p^2/\omega^2)^{-1}$. Most of the radiation is produced in this distance. Here θ is the x-ray emission angle, characteristically $1/\gamma$. For $\theta = 1/\gamma$ the formation length has a maximum at $d(\gamma\omega_p/\sqrt{2}) = \gamma c/\sqrt{2}\,\omega_p$. In practical situations it is tens of μm.

Since the useful x-ray yield from a single interface is low, in practical detectors it is enhanced by using a stack of N foil radiators—foils L thick, where L is typically several formation lengths—separated by gas-filled gaps. The amplitudes at successive interfaces interfere to cause oscillations about the single-interface spectrum. At increasing frequencies above the position of the last interference maximum ($L/d(w) = \pi/2$), the formation zones, which have opposite phase, overlap more and more and the spectrum saturates, $dI/d\omega$ approaching zero as $L/d(\omega) \to 0$. This is illustrated in Fig. 34.27 for a realistic detector configuration.

Although one might expect the intensity of coherent radiation from the stack of foils to be proportional to N^2, the angular dependence of the formation length conspires to make the intensity $\propto N$.

35. Particle Detectors at Accelerators

Revised 2019. See the various sections for authors.

35.1 Introduction

This review summarizes the detector technologies employed at accelerator particle physics experiments. Several of these detectors are also used in a non-accelerator context and examples of such applications will be provided. The detector techniques which are specific to non-accelerator particle physics experiments are the subject of Chap. 36. More detailed discussions of detectors and their underlying physics can be found in books by Ferbel [1], Kleinknecht [2], Knoll [3], Green [4], Leroy & Rancoita [5], and Grupen [6].

In Table 35.1 are given typical resolutions and deadtimes of common charged particle detectors. The quoted numbers are usually based on typical devices, and should be regarded only as rough approximations for new designs. The spatial resolution refers to the intrinsic detector resolution, i.e. without multiple scattering. We note that analog detector readout can provide better spatial resolution than digital readout by measuring the deposited charge in neighboring channels. Quoted ranges attempt to be representative of both possibilities. The time resolution is defined by how accurately the time at which a particle crossed the detector can be determined. The deadtime is the minimum separation in time between two resolved hits on the same channel. Typical performance of calorimetry and particle identification are provided in the relevant sections below. Further discussion and all references may be found in the full *Review.*

Table 35.1: Typical resolutions and deadtimes of common charged particle detectors. Revised November 2011.

Detector Type	Intrinsic Spatial Resolution (rms)	Time Resolution	Dead Time
Resistive plate chamber	$\lesssim 10$ mm	1 ns (50 ps) *	—
Streamer chamber	300 μm †	2 μs	100 ms
Liquid argon drift [7]	∼175–450 μm	∼200 ns	∼2 μs
Scintillation tracker	∼100 μm	100 ps/n ‡	10 ns
Bubble chamber	10–150 μm	1 ms	50 ms §
Proportional chamber	50–100 μm ¶	2 ns	20-200 ns
Drift chamber	50–100 μm	2 ns ‖	20-100 ns
Micro-pattern gas detectors	30–40 μm	< 10 ns	10-100 ns
Silicon strip	pitch/(3 to 7) **	few ns ††	$\lesssim$50 ns ††
Silicon pixel	$\lesssim$10 μm	few ns ††	$\lesssim$ 50 ns ††
Emulsion	1 μm	—	—

* For multiple-gap RPCs.

† 300 μm is for 1 mm pitch (wirespacing/$\sqrt{12}$).

‡ n = index of refraction.

§ Multiple pulsing time.

¶ Delay line cathode readout can give ±150 μm parallel to anode wire.

‖ For two chambers.

**The highest resolution (“7”) is obtained for small-pitch detectors ($\lesssim$ 25 μm)

††Limited by the readout electronics [8]

37. Radioactivity and Radiation Protection

Revised August 2019 by S. Roesler and M. Silari (CERN).

37.1. Definitions

The International Commission on Radiation Units and Measurements (ICRU) recommends the use of SI units. Therefore we list SI units first, followed by cgs (or other common) units in parentheses, where they differ.

- **Activity** (unit: Becquerel):
  1 Bq = 1 disintegration per second (= 27 pCi).
- **Absorbed dose** (unit: gray): The absorbed dose is the energy imparted by ionizing radiation in a volume element of a specified material divided by the mass of this volume element.
  1 Gy = 1 J/kg (= 10^4 erg/g = 100 rad)
  = 6.24×10^{12} MeV/kg deposited energy.
- **Kerma** (unit: gray): Kerma is the sum of the initial kinetic energies of all charged particles liberated by indirectly ionizing particles in a volume element of the specified material divided by the mass of this volume element.
- **Exposure** (unit: C/kg of air [= 3880 Roentgen†]): The exposure is a measure of photon fluence at a certain point in space integrated over time, in terms of ion charge of either sign produced by secondary electrons in a small volume of air about the point. Implicit in the definition is the assumption that the small test volume is embedded in a sufficiently large uniformly irradiated volume that the number of secondary electrons entering the volume equals the number leaving (so-called charged particle equilibrium).

Table 37.1: Radiation weighting factors, w_R.

Radiation type	w_R
Photons	1
Electrons and muons	1
Neutrons, $E_n < 1$ MeV	$2.5 + 18.2 \times \exp[-(\ln E_n)^2/6]$
$1 \text{ MeV} \leq E_n \leq 50$ MeV	$5.0 + 17.0 \times \exp[-(\ln(2E_n))^2/6]$
$E_n > 50$ MeV	$2.5 + 3.25 \times \exp[-(\ln(0.04E_n))^2/6]$
Protons and charged pions	2
Alpha particles, fission fragments, heavy ions	20

- **Equivalent dose** (unit: Sievert [= 100 rem (roentgen equivalent in man)]): The equivalent dose H_T in an organ or tissue T is equal to the sum of the absorbed doses $D_{T,R}$ in the organ or tissue caused by different radiation types R weighted with so-called radiation weighting factors w_R:

$$H_T = \sum_R w_R \times D_{T,R} \ . \tag{37.2}$$

† This unit is somewhat historical, but appears on some measuring instruments. One R is the amount of radiation required to liberate positive and negative charges of one electrostatic unit of charge in 1 cm^3 of air at standard temperature and pressure (STP)

It expresses long-term risks (primarily cancer and leukemia) from low-level chronic exposure. The values for w_R recommended recently by ICRP [2] are given in Table 37.1.

• **Effective dose** (unit: Sievert): The sum of the equivalent doses, weighted by the tissue weighting factors w_T ($\sum_T w_T = 1$) of several organs and tissues T of the body that are considered to be most sensitive [2], is called "effective dose" E:

$$E = \sum_T w_T \times H_T \ . \tag{37.3}$$

37.2. Radiation levels [4]

• **Natural annual background**, all sources: Most world areas, whole-body equivalent dose rate $\approx$ (1.0–13) mSv (0.1–1.3 rem). Can range up to 50 mSv (5 rem) in certain areas. U.S. average $\approx$ 3.6 mSv, including $\approx$ 2 mSv ($\approx$ 200 mrem) from inhaled natural radioactivity, mostly radon and radon daughters. (Average is for a typical house and varies by more than an order of magnitude. It can be more than two orders of magnitude higher in poorly ventilated mines. 0.1–0.2 mSv in open areas.)

• **Cosmic ray background** (sea level, mostly muons): $\sim 1\ \text{min}^{-1}\ \text{cm}^{-2}\ \text{sr}^{-1}$. For more accurate estimates and details, see the Cosmic Rays section (Sec. 30 of this *Review*).

• **Fluence** (per cm^2) to deposit one Gy, assuming uniform irradiation:

$\approx$ (**charged particles**) $6.24\times10^9/(dE/dx)$, where dE/dx (MeV g^{-1} cm^2), the energy loss per unit length, may be obtained from Figs. 34.2 and 34.4 in Sec. 34 of the *Review*, and `pdg.lbl.gov/AtomicNuclearProperties`.

$\approx 3.5 \times 10^9$ cm^{-2} minimum-ionizing singly-charged particles in carbon.

$\approx$ (**photons**) $6.24\times10^9/[Ef/\ell]$, for photons of energy E (MeV), attenuation length ℓ (g cm^{-2}), and fraction $f \lesssim 1$ expressing the fraction of the photon's energy deposited in a small volume of thickness $\ll \ell$ but large enough to contain the secondary electrons.

$\approx 2 \times 10^{11}$ photons cm^{-2} for 1 MeV photons on carbon ($f \approx 1/2$).

37.3. Health effects of ionizing radiation

• **Recommended limits of effective dose to radiation workers (whole-body dose):***

EU/Switzerland: 20 mSv yr^{-1}

U.S.: 50 mSv yr^{-1} (5 rem yr^{-1})†

• **Lethal dose**: The whole-body dose from penetrating ionizing radiation resulting in 50% mortality in 30 days (assuming no medical treatment) is 2.5–4.5 Gy (250–450 rad), as measured internally on body longitudinal center line. Surface dose varies due to variable body attenuation and may be a strong function of energy.

• **Cancer induction by low LET radiation**: The cancer induction probability is about 5% per Sv on average for the entire population [2].

Footnotes:

* The ICRP recommendation [2] is 20 mSv yr^{-1} averaged over 5 years, with the dose in any one year $\leq$ 50 mSv.

† Many laboratories in the U.S. and elsewhere set lower limits.

See full *Review* for references and further details.

38. Commonly Used Radioactive Sources

Table 38.1. Revised September 2019 by D.E. Groom (LBNL).

			Particle		Photon	
Nuclide	Half-life	Type of decay	Energy (MeV)	Emission prob.	Energy (MeV)	Emission prob.
${}^{22}_{11}$Na	2.603 y	β^+, EC	0.546	90%	0.511	Annih.
					1.275	100%
${}^{51}_{24}$Cr	27.70 d	EC			0.320	10%
					V K x rays	100%
			Neutrino calibration source			
${}^{54}_{25}$Mn	0.855 y	EC			0.835	100%
					Cr K x rays	26%
${}^{55}_{26}$Fe	2.747 y	EC			Mn K x rays:	
					0.00590	24.4%
					0.00649	2.86%
${}^{57}_{27}$Co	271.8 d	EC			0.014	9%
					0.122	86%
					0.136	11%
					Fe K x rays	58%
${}^{60}_{27}$Co	5.271 y	β^-	0.317	99.9%	1.173	99.9%
					1.333	99.9%
${}^{68}_{32}$Ge	271.0 d	EC			Ga K x rays	42%
$\rightarrow$ ${}^{68}_{31}$Ga	67.8 m	β^+, EC	1.899	90%	0.511	Annih.
					1.077	3%
${}^{90}_{38}$Sr	28.8 y	β^-	0.546	100%		
$\rightarrow$ ${}^{90}_{39}$Y	2.67 d	β^-	2.279	100%		
${}^{106}_{44}$Ru	371.5 d	β^-	0.039	100%		
$\rightarrow$ ${}^{106}_{45}$Rh	30.1 s	β^-	3.546	79%	0.512	21%
					0.622	10%
${}^{109}_{48}$Cd	1.265 y	EC	0.063 e^-	42%	0.088	3.7%
			0.084 e^-	44%	Ag K x rays	100%
${}^{113}_{50}$Sn	115.1 d	EC	0.364 e^-	28%	0.392	65%
			0.388 e^-	6%	In K x rays	97%
${}^{137}_{55}$Cs	30.0 y	β^-	0.514	94%	0.662	85%
			1.176	6%		

$^{133}_{56}$Ba	10.55 y	EC	0.045 e^-	50%	0.081	33%
			0.075 e^-	6%	0.356	62%
					Cs K x rays 121%	
$^{152}_{63}$Eu	13.537 y	EC		72.1%	Many γ's	
		β^-		27.9%	0.1218–1.408 MeV	
$^{207}_{83}$Bi	32.9 y	EC	0.481 e^-	2%	0.569	98%
			0.975 e^-	7%	1.063	75%
			1.047 e^-	2%	1.770	7%
					Pb K x rays 78%	
$^{228}_{90}$Th	1.912 y	6α:	5.341 to 8.785		0.239	44%
		$3\beta^-$:	0.334 to 2.246		0.583	31%
					2.614	36%
(→$^{224}_{88}$Ra	→ $^{220}_{86}$Rn	→ $^{216}_{84}$Po	→ $^{212}_{82}$Pb	→ $^{212}_{83}$Bi	→ $^{212}_{84}$Po)	
(361 d	55.8 s	0.148 s	10.64 h	60.54 m	300 ns)	
$^{241}_{95}$Am	432.6 y	α	5.443	13%	0.060	36%
			5.486	84%	Np L x rays 38%	
$^{241}_{95}$Am/Be	432.6 y	6×10^{-5} neutrons ($\langle E \rangle = 4$ MeV) and $4 \times 10^{-5}\gamma$'s (4.43 MeV from $^{9}_{4}$Be(α, n))				
$^{244}_{96}$Cm	18.11 y	α	5.763	24%	Pu L x rays ~ 9%	
			5.805	76%		
$^{252}_{98}$Cf	2.645 y	α (97%)	6.076	15%		
			6.118	82%		
	Fission (3.1%): Average 7.8 γ's/fission; $\langle E_\gamma \rangle = 0.88$ MeV; ≈ 4 neutrons/fission; $\langle E_n \rangle = 2.14$ MeV					

"Emission probability" is the probability per decay of a given emission; because of cascades these may total more than 100%. Only principal emissions are listed. EC means electron capture, and e^- means monoenergetic internal conversion (Auger) electron. The intensity of 0.511 MeV e^+e^- annihilation photons depends upon the number of stopped positrons. Endpoint $\beta^\pm$ energies are listed. In some cases when energies are closely spaced, the γ-ray values are approximate weighted averages. Radiation from short-lived daughter isotopes is included where relevant.

Half-lives, energies, and intensities may be found in `www-pub.iaea.org/books/IAEABooks/7551/Update-of-X-Ray-and-Gamma-Ray-Decay-Data-Standards-for-Detector-Calibration-and-Other-Applications`, `IAEA` (2007) or Nuclear Data Sheets (`www.journals.elsevier.com/nuclear-data-sheets`) (2007).
Neutron sources: See *e.g.* "Neutron Calibration Sources in the Daya Bay Experiment," J. Liu *et al.*, Nuclear Instrum. Methods **A797,** 260 (2005) (arXiv.1504.07911).

$^{51}_{24}$Cr calibration of neutrino detectors is discussed in *e.g.* J.N. Abdurashitov *et al.* [SAGE Collaboration], Phys. Rev. **C59**, 2246 (1999). The use of $^{75}_{34}$Se and other isotopes has been proposed.

39. Probability

Revised August 2019 by G. Cowan (RHUL).

The following is a much-shortened version of Sec. 39 of the full *Review*. Equation, section, and figure numbers follow the *Review*.

39.2 Random variables

• *Probability density function* (p.d.f.): x is a *random variable*.
Continuous: $f(x;\theta)dx$ = probability x is between x to $x + dx$, given parameter(s) θ;
Discrete: $f(x;\theta)$ = probability of x given θ.

• *Cumulative distribution function*:

$$F(a) = \int_{-\infty}^{a} f(x)\,dx. \tag{39.6}$$

Here and below, if x is discrete-valued, the integral is replaced by a sum. The endpoint a is indcluded in the integral or sum.

• *Expectation values*: Given a function u:

$$E[u(x)] = \int_{-\infty}^{\infty} u(x)\,f(x)\,dx. \tag{39.7}$$

• *Moments*:

$$n^{th} \text{ moment of a random variable: } \alpha_n = E[x^n], \tag{39.8a}$$

$$n^{th} \text{ central moment: } m_n = E[(x-\alpha_1)^n]. \tag{39.8b}$$

$$\text{Mean: } \mu \equiv \alpha_1\ , \tag{39.9a}$$

$$\text{Variance: } \sigma^2 \equiv V[x] \equiv m_2 = \alpha_2 - \mu^2\ . \tag{39.9b}$$

Coefficient of skewness: $\gamma_1 \equiv m_3/\sigma^3$.
Kurtosis: $\gamma_2 = m_4/\sigma^4 - 3$.
Median: $F(x_{\text{med}}) = 1/2$.

• *Marginal* p.d.f.: Let x,y be two random variables with joint p.d.f. $f(x,y)$.

$$f_1(x) = \int_{-\infty}^{\infty} f(x,y)\,dy; \qquad f_2(y) = \int_{-\infty}^{\infty} f(x,y)\,dx. \tag{39.10}$$

• *Conditional* p.d.f.:

$$f_4(x|y) = f(x,y)/f_2(y);\ \ f_3(y|x) = f(x,y)/f_1(x).$$

• *Bayes' theorem*:

$$f_4(x|y) = \frac{f_3(y|x)f_1(x)}{f_2(y)} = \frac{f_3(y|x)f_1(x)}{\int f_3(y|x')f_1(x')\,dx'}\ . \tag{39.11}$$

• *Correlation coefficient and covariance*:

$$\mu_x = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} x f(x,y)\, dx\, dy, \qquad (39.12)$$

$$\rho_{xy} = E\left[(x-\mu_x)(y-\mu_y)\right]/\sigma_x\,\sigma_y \equiv \mathrm{cov}[x,y]/\sigma_x\,\sigma_y,$$

$$\sigma_x = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} (x-\mu_x)^2\, f(x,y)\, dx\, dy. \text{ Note } \rho_{xy}^2 \le 1.$$

• *Independence*: x,y are independent if and only if $f(x,y) = f_1(x)\cdot f_2(y)$; then $\rho_{xy} = 0$, $E[u(x)\, v(y)] = E[u(x)]\; E[v(y)]$ and $V[x+y] = V[x]+V[y]$.

• *Change of variables*: From $\boldsymbol{x} = (x_1,\ldots,x_n)$ to $\boldsymbol{x} = (y_1,\ldots,y_n)$: $g(\boldsymbol{y}) = f(\boldsymbol{x}(\boldsymbol{y}))\cdot|J|$ where $|J|$ is the absolute value of the determinant of the Jacobian $J_{ij} = \partial x_i/\partial y_j$. For discrete variables, use $|J| = 1$.

39.3 Characteristic functions

Given a pdf $f(x)$ for a continuous random variable x, the characteristic function $\phi(u)$ is given by (31.6). Its derivatives are related to the algebraic moments of x by (31.7).

$$\phi(u) = E\left[e^{iux}\right] = \int_{-\infty}^{\infty} e^{iux} f(x)\, dx\ . \qquad (39.17)$$

$$i^{-n}\ \frac{d^n\phi}{du^n}\bigg|_{u=0} = \int_{-\infty}^{\infty} x^n f(x)\, dx = \alpha_n\ . \qquad (39.18)$$

If the p.d.f.s $f_1(x)$ and $f_2(y)$ for independent random variables x and y have characteristic functions $\phi_1(u)$ and $\phi_2(u)$, then the characteristic function of the weighted sum $ax+by$ is $\phi_1(au)\phi_2(bu)$. The additional rules for several important distributions (*e.g.*, that the sum of two Gaussian distributed variables also follows a Gaussian distribution) easily follow from this observation.

39.4 Some probability distributions

See Table 39.1.

39.4.2 *Poisson distribution*

The Poisson distribution $f(n;\nu)$ gives the probability of finding exactly n events in a given interval of x (*e.g.*, space or time) when the events occur independently of one another and of x at an average rate of ν per the given interval. The variance σ^2 equals ν. It is the limiting case $p\to 0$, $N\to\infty$, $Np=\nu$ of the binomial distribution. The Poisson distribution approaches the Gaussian distribution for large ν.

39.4.3 *Normal or Gaussian distribution*

Its cumulative distribution, for mean 0 and variance 1, is often tabulated as the *error function*

$$F(x;0,1) = \frac{1}{2}\left[1+\mathrm{erf}(x/\sqrt{2})\right]. \qquad (39.24)$$

For mean μ and variance σ^2, replace x by $(x-\mu)/\sigma$.
$P(x \text{ in range } \mu\pm\sigma) = 0.6827$,
$P(x \text{ in range } \mu\pm 0.6745\sigma) = 0.5$,
$E[|x-\mu|] = \sqrt{2/\pi}\sigma = 0.7979\sigma$,

half-width at half maximum $= \sqrt{2\ln 2}\cdot\sigma = 1.177\sigma$.

For n Gaussian random variables $\boldsymbol{x}_i$, the joint p.d.f. is the multivariate Gaussian:

$$f(\boldsymbol{x};\boldsymbol{\mu},V) = \frac{1}{(2\pi)^{n/2}\sqrt{|V|}}\exp\left[-\frac{1}{2}(\boldsymbol{x}-\boldsymbol{\mu})^T V^{-1}(\boldsymbol{x}-\boldsymbol{\mu})\right],\ |V|>0\ . \tag{39.25}$$

V is the $n\times n$ *covariance matrix*; $V_{ij}\equiv E[(x_i-\mu_i)(x_j-\mu_j)]\equiv\rho_{ij}\,\sigma_i\,\sigma_j$, and $V_{ii}=V[x_i]$; $|V|$ is the determinant of V. For $n=2$, $f(\boldsymbol{x};\boldsymbol{\mu},V)$ is

$$f(x_1,x_2;\ \mu_1,\mu_2,\sigma_1,\sigma_2,\rho) = \frac{1}{2\pi\sigma_1\sigma_2\sqrt{1-\rho^2}}\times\ \exp\left\{\frac{-1}{2(1-\rho^2)}\right.$$

$$\left.\left[\frac{(x_1-\mu_1)^2}{\sigma_1^2} - \frac{2\rho(x_1-\mu_1)(x_2-\mu_2)}{\sigma_1\sigma_2} + \frac{(x_2-\mu_2)^2}{\sigma_2^2}\right]\right\}. \tag{39.26}$$

The marginal distribution of any x_i is a Gaussian with mean μ_i and variance V_{ii}. V is $n\times n$, symmetric, and positive definite. Therefore for any vector $\boldsymbol{X}$, the quadratic form $\boldsymbol{X}^T V^{-1}\boldsymbol{X}=C$, where C is any positive number, traces an n-dimensional ellipsoid as $\boldsymbol{X}$ varies. If $X_i=x_i-\mu_i$, then C is a random variable obeying the χ^2 distribution with n degrees of freedom, discussed in the following section. The probability that $\boldsymbol{X}$ corresponding to a set of Gaussian random variables x_i lies outside the ellipsoid characterized by a given value of C $(=\chi^2)$ is given by $1-F_{\chi^2}(C;n)$, where F_{χ^2} is the cumulative χ^2 distribution. This may be read from Fig. 40.1. For example, the "s-standard-deviation ellipsoid" occurs at $C=s^2$. For the two-variable case ($n=2$), the point $\boldsymbol{X}$ lies outside the one-standard-deviation ellipsoid with 61% probability. The use of these ellipsoids as indicators of probable error is described in Sec. 40.4.2.2; the validity of those indicators assumes that $\boldsymbol{\mu}$ and V are correct.

39.4.5 χ^2 *distribution*

If $x_1,\ldots,x_n$ are independent Gaussian random variables, the sum $z=\sum_{i=1}^{n}(x_i-\mu_i)^2/\sigma_i^2$ follows the χ^2 p.d.f. with n *degrees of freedom*, which we denote by $\chi^2(n)$. More generally, for n correlated Gaussian variables as components of a vector $\boldsymbol{X}$ with covariance matrix V, $z=\boldsymbol{X}^T V^{-1}\boldsymbol{X}$ follows $\chi^2(n)$ as in the previous section. For a set of z_i, each of which follows $\chi^2(n_i)$, $\sum z_i$ follows $\chi^2(\sum n_i)$. For large n, the χ^2 p.d.f. approaches a Gaussian with mean $\mu=n$ and variance $\sigma^2=2n$.

The χ^2 p.d.f. is often used in evaluating the level of compatibility between observed data and a hypothesis for the p.d.f. that the data might follow. This is discussed further in Sec. 40.3.2 on tests of goodness-of-fit.

39.4.7 *Gamma distribution*

For a process that generates events as a function of x (*e.g.*, space or time) according to a Poisson distribution, the distance in x from an arbitrary starting point (which may be some particular event) to the k^{th} event follows a *gamma* distribution, $f(x;\lambda,k)$. The Poisson parameter μ is λ per unit x. The special case $k=1$ (*i.e.*, $f(x;\lambda,1)=\lambda e^{-\lambda x}$) is called the *exponential* distribution. A sum of k' exponential random variables x_i is distributed as $f(\sum x_i;\lambda,k')$.

The parameter k is not required to be an integer. For $\lambda=1/2$ and $k=n/2$, the gamma distribution reduces to the $\chi^2(n)$ distribution.

See the full *Review* for further discussion and all references.

Table 39.1: Some common probability density functions, with corresponding characteristic functions and means and variances. In the Table, $\Gamma(k)$ is the gamma function, equal to $(k-1)!$ when k is an integer.

Distribution	Probability density function f (variable; parameters)	Characteristic function $\phi(u)$	Mean	Variance
Uniform	$f(x;a,b) = \begin{cases} 1/(b-a) & a \le x \le b \\ 0 & \text{otherwise} \end{cases}$	$\frac{e^{ibu}-e^{iau}}{(b-a)iu}$	$\frac{a+b}{2}$	$\frac{(b-a)^2}{12}$
Binomial	$f(r;N,p) = \frac{N!}{r!(N-r)!}\; p^r q^{N-r}$ $r = 0,1,2,\ldots,N;\quad 0 \le p \le 1;\quad q = 1-p$	$(q+pe^{iu})^N$	Np	Npq
Poisson	$f(n;\nu) = \frac{\nu^n e^{-\nu}}{n!};\; n = 0,1,2,\ldots;\; \nu > 0$	$\exp[\nu(e^{iu}-1)]$	ν	ν
Normal (Gaussian)	$f(x;\mu,\sigma^2) = \frac{1}{\sigma\sqrt{2\pi}}\; \exp(-(x-\mu)^2/2\sigma^2)$	$\exp(i\mu u - \frac{1}{2}\sigma^2 u^2)$	μ	σ^2
Multivariate Gaussian	$f(\boldsymbol{x};\boldsymbol{\mu},\boldsymbol{V}) = \frac{1}{(2\pi)^{n/2}\sqrt{\lvert V\rvert}}$ $\times \exp\left[-\frac{1}{2}(\boldsymbol{x}-\boldsymbol{\mu})^T V^{-1}(\boldsymbol{x}-\boldsymbol{\mu})\right]$ $-\infty < x_j < \infty;\quad -\infty < \mu_j < \infty;\quad \lvert V\rvert > 0$	$\exp\left[i\boldsymbol{\mu}\cdot\boldsymbol{u} - \frac{1}{2}\boldsymbol{u}^T V \boldsymbol{u}\right]$	$\boldsymbol{u}$	V_{jk}
χ^2	$f(z;n) = \frac{z^{n/2-1}e^{-z/2}}{2^{n/2}\Gamma(n/2)};\quad z \ge 0$	$(1-2iu)^{-n/2}$	n	$2n$
Student's t	$f(t;n) = \frac{1}{\sqrt{n\pi}}\;\frac{\Gamma[(n+1)/2]}{\Gamma(n/2)}\left(1+\frac{t^2}{n}\right)^{-(n+1)/2}$ $-\infty < t < \infty;\qquad n not required to be integer$	—	0 for $n > 1$	$n/(n-2)$ for $n > 2$
Gamma	$f(x;\lambda,k) = \frac{x^{k-1}\lambda^k e^{-\lambda x}}{\Gamma(k)};\quad 0 \le x < \infty\;;$ k not required to be integer	$(1-iu/\lambda)^{-k}$	k/λ	k/λ^2

40. Statistics

Revised October 2019 by G. Cowan (RHUL).

This chapter gives an overview of statistical methods used in high-energy physics. In statistics, we are interested in using a given sample of data to make inferences about a probabilistic model, *e.g.*, to assess the model's validity or to determine the values of its parameters. There are two main approaches to statistical inference, which we may call frequentist and Bayesian.

40.2 Parameter estimation

An *estimator* $\widehat{\theta}$ (written with a hat) is a function of the data used to estimate the value of the parameter θ.

40.2.1 *Estimators for mean, variance, and median*

Suppose we have a set of n independent measurements, $x_1, \ldots, x_n$, each assumed to follow a p.d.f. with unknown mean μ and unknown variance σ^2 (the measurements do not necessarily have to follow a Gaussian distribution). Then

$$\widehat{\mu} = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad (40.5)$$

$$\widehat{\sigma^2} = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \widehat{\mu})^2 \qquad (40.6)$$

are unbiased estimators of μ and σ^2. The variance of $\widehat{\mu}$ is σ^2/n and the variance of $\widehat{\sigma^2}$ is

$$V\left[\widehat{\sigma^2}\right] = \frac{1}{n}\left(m_4 - \frac{n-3}{n-1}\sigma^4\right) , \qquad (40.7)$$

where m_4 is the 4^{th} central moment of x (see Eq. (39.8)). For Gaussian distributed x_i, this becomes $2\sigma^4/(n-1)$ for any $n \geq 2$, and for large n the standard deviation of $\widehat{\sigma}$ is $\sigma/\sqrt{2n}$.

If the x_i have different, known variances σ_i^2, then the weighted average

$$\widehat{\mu} = \frac{1}{w}\sum_{i=1}^{n} w_i x_i , \qquad (40.8)$$

where $w_i = 1/\sigma_i^2$ and $w = \sum_i w_i$, is an unbiased estimator for μ with a smaller variance than an unweighted average. The standard deviation of $\widehat{\mu}$ is $1/\sqrt{w}$.

40.2.2 *The method of maximum likelihood*

Suppose we have a set of measured quantities $\boldsymbol{x}$ and the likelihood $L(\boldsymbol{\theta}) = P(\boldsymbol{x}|\boldsymbol{\theta})$ for a set of parameters $\boldsymbol{\theta} = (\theta_1, \ldots, \theta_N)$. The *maximum likelihood* (ML) estimators for $\boldsymbol{\theta}$ can be found by solving the *likelihood equations*,

$$\frac{\partial \ln L}{\partial \theta_i} = 0 , \qquad i = 1, \ldots, N . \qquad (40.9)$$

In the large sample limit, the s times the standard deviations σ_i of the estimators for the parameters can be obtained from the hypersurface defined by the $\boldsymbol{\theta}$ such that

$$\ln L(\boldsymbol{\theta}) = \ln L_{\max} - s^2/2 , \qquad (40.13)$$

40.2.3 *The method of least squares*

For Gaussian distributed measurements y_i with mean $\mu(x_i;\boldsymbol{\theta})$ and known variance σ_i^2, the log-likelihood function contains the sum of squares

$$\chi^2(\boldsymbol{\theta}) = -2\ln L(\boldsymbol{\theta}) + \text{ constant } = \sum_{i=1}^{N} \frac{(y_i - \mu(x_i;\boldsymbol{\theta}))^2}{\sigma_i^2} . \tag{40.19}$$

If the y_i have a covariance matrix $V_{ij} = \mathrm{cov}[y_i, y_j]$, then the estimators are determined by the minimum of

$$\chi^2(\boldsymbol{\theta}) = (\boldsymbol{y} - \boldsymbol{\mu}(\boldsymbol{\theta}))^T V^{-1}(\boldsymbol{y} - \boldsymbol{\mu}(\boldsymbol{\theta})) , \tag{40.20}$$

40.3 Statistical tests

40.3.1 *Hypothesis tests*

A frequentist *test* of a hypothesis (often called the null hypothesis, H_0) is a rule that states for which data values $\boldsymbol{x}$ the hypothesis is rejected. A critical region w is specified such that there is no more than a given probability α, called the *size* or *significance level* of the test, to find $\boldsymbol{x} \in w$. If the data are discrete, it may not be possible to find a critical region with exact probability content α, and thus we require $P(\boldsymbol{x} \in w|H_0) \leq \alpha$. If the data are observed in the critical region, H_0 is rejected.

The critical region is not unique, and generally defined relative to some alternative hypothesis (or set of alternatives) H_1. To maximize the power of the test of H_0 with respect to the alternative H_1, the *Neyman–Pearson lemma* states that the critical region w should be chosen such that for all data values $\boldsymbol{x}$ inside w, the likelihood ratio

$$\lambda(\boldsymbol{x}) = \frac{f(\boldsymbol{x}|H_1)}{f(\boldsymbol{x}|H_0)} \tag{40.44}$$

is greater than or equal to a given constant c_α, and everywhere outside the critical region one has $\lambda(\boldsymbol{x}) < c_\alpha$, where the value of c_α is determined by the size of the test α. Here H_0 and H_1 must be simple hypotheses, *i.e.*, they should not contain undetermined parameters.

40.3.2 *Tests of significance (goodness-of-fit)*

Often one wants to quantify the level of agreement between the data and a hypothesis without explicit reference to alternative hypotheses. This can be done by defining a statistic t whose value reflects in some way the level of agreement between the data and the hypothesis. For example, if t is defined such that large values correspond to poor agreement with the hypothesis, then the p-value would be

$$p = \int_{t_{\rm obs}}^{\infty} f(t|H_0)\, dt , \tag{40.45}$$

where $t_{\rm obs}$ is the value of the statistic obtained in the actual experiment.

40.3.2.1 *Goodness-of-fit with the method of least squares*

For Poisson measurements n_i with variances $\sigma_i^2 = \mu_i$, the χ^2 (40.19) becomes *Pearson's χ^2 statistic*,

$$\chi^2 = \sum_{i=1}^{N} \frac{(n_i - \mu_i)^2}{\mu_i} . \tag{40.53}$$

Assuming the goodness-of-fit statistic follows a χ^2 p.d.f., the p-value for the hypothesis is then

$$p = \int_{\chi^2}^{\infty} f(z; n_{\rm d})\, dz \ , \tag{40.54}$$

where $f(z; n_{\rm d})$ is the χ^2 p.d.f. and $n_{\rm d}$ is the appropriate number of degrees of freedom. Values are shown in Fig. 40.1. The p-values obtained for different values of $\chi^2/n_{\rm d}$ are shown in Fig. 40.2.

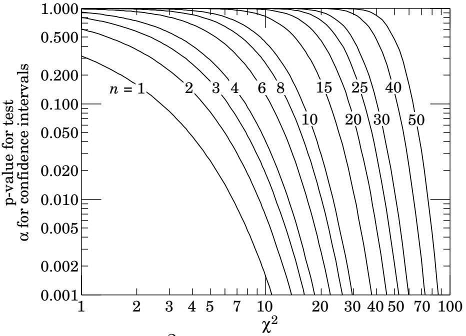


Figure 40.1: One minus the χ^2 cumulative distribution, $1 - F(\chi^2; n)$, for n degrees of freedom. This gives the p-value for the χ^2 goodness-of-fit test as well as one minus the coverage probability for confidence regions (see Sec. 40.4.2.2).

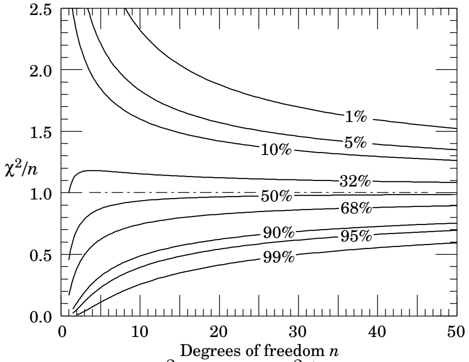


Figure 40.2: The 'reduced' χ^2, equal to χ^2/n, for n degrees of freedom. The curves show as a function of n the χ^2/n that corresponds to a given p-value.

40.3.3 *Bayes factors*

In Bayesian statistics, one could reject a hypothesis H if its posterior probability $P(H|\boldsymbol{x})$ is sufficiently small. The full prior probability for two models (hypotheses) H_i and H_j can be written in the form

$$\pi(H_i, \boldsymbol{\theta}_i) = P(H_i)\pi(\boldsymbol{\theta}_i|H_i) \ . \tag{40.55}$$

The *Bayes factor* is defined as

$$B_{ij} = \frac{\int P(\boldsymbol{x}|\boldsymbol{\theta}_i, H_i)\pi(\boldsymbol{\theta}_i|H_i)\, d\boldsymbol{\theta}_i}{\int P(\boldsymbol{x}|\boldsymbol{\theta}_j, H_j)\pi(\boldsymbol{\theta}_j|H_j)\, d\boldsymbol{\theta}_j} . \tag{40.58}$$

This gives what the ratio of posterior probabilities for models i and j would be if the overall prior probabilities for the two models were equal.

40.4 Intervals and limits

40.4.1 *Bayesian intervals*

A Bayesian or credible interval) $[\theta_{\rm lo}, \theta_{\rm up}]$ can be determined which contains a given fraction $1-\alpha$ of the posterior probability, *i.e.*,

$$1 - \alpha = \int_{\theta_{\rm lo}}^{\theta_{\rm up}} p(\theta|\boldsymbol{x})\, d\theta . \tag{40.60}$$

40.4.2 *Frequentist confidence intervals*

40.4.2.1 *The Neyman construction for confidence intervals*

Given a p.d.f. $f(x;\theta)$, we can find using a pre-defined rule and probability $1-\alpha$ for every value of θ, a set of values $x_1(\theta,\alpha)$ and $x_2(\theta,\alpha)$ such that

$$P(x_1 < x < x_2; \theta) = \int_{x_1}^{x_2} f(x;\theta)\, dx \geq 1 - \alpha . \tag{40.67}$$

40.4.2.2 *Gaussian distributed measurements*

When the data consists of a single random variable x that follows a Gaussian distribution with known σ, the probability that the measured value x will fall within $\pm\delta$ of the true value μ is

$$\begin{aligned} 1 - \alpha &= \frac{1}{\sqrt{2\pi}\sigma} \int_{\mu-\delta}^{\mu+\delta} e^{-(x-\mu)^2/2\sigma^2}\, dx \\ &= \mathrm{erf}\left(\frac{\delta}{\sqrt{2}\,\sigma}\right) = 2\Phi\left(\frac{\delta}{\sigma}\right) - 1 , \end{aligned} \tag{40.70}$$

Fig. 40.4 shows a $\delta = 1.64\sigma$ confidence interval unshaded. Values of α for other frequently used choices of δ are given in Table 40.1.

Table 40.1: Area of the tails α outside $\pm\delta$ from the mean of a Gaussian distribution.

α	δ	α	δ
0.3173	1σ	0.2	1.28σ
4.55×10^{-2}	2σ	0.1	1.64σ
2.7×10^{-3}	3σ	0.05	1.96σ
6.3×10^{-5}	4σ	0.01	2.58σ
5.7×10^{-7}	5σ	0.001	3.29σ
2.0×10^{-9}	6σ	10^{-4}	3.89σ

We can set a one-sided (upper or lower) limit by excluding above $x+\delta$ (or below $x-\delta$). The values of α for such limits are half the values in Table 40.1. Values of $\Delta\chi^2$ or $2\Delta \ln L$ are given in Table 40.2 for several values of the coverage probability $1-\alpha$ and number of fitted parameters m.

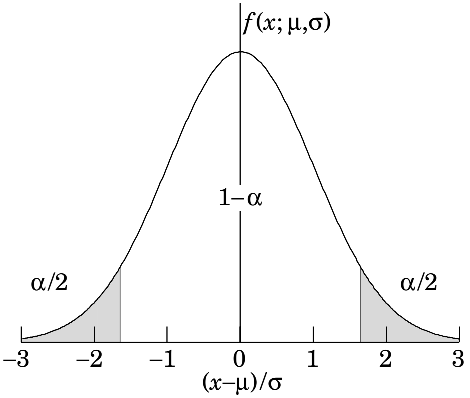


Figure 40.4: Illustration of a symmetric 90% confidence interval (unshaded) for a Gaussian-distributed measurement of a single quantity. Integrated probabilities, defined by $\alpha = 0.1$, are as shown.

Table 40.2: Values of $\Delta\chi^2$ or $2\Delta \ln L$ corresponding to a coverage probability $1-\alpha$ in the large data sample limit, for joint estimation of m parameters.

$(1-\alpha)$ (%)	$m = 1$	$m = 2$	$m = 3$
68.27	1.00	2.30	3.53
90.	2.71	4.61	6.25
95.	3.84	5.99	7.82
95.45	4.00	6.18	8.03
99.	6.63	9.21	11.34
99.73	9.00	11.83	14.16

40.4.2.3 *Poisson or binomial data*

For Poisson distributed n, the upper and lower limits on the mean value μ from the Neyman procedure are

$$\mu_{\rm lo} = \frac{1}{2} F^{-1}_{\chi^2}(\alpha_{\rm lo}; 2n) \ , \tag{40.76a}$$

$$\mu_{\rm up} = \frac{1}{2} F^{-1}_{\chi^2}(1-\alpha_{\rm up}; 2(n+1)) \ , \tag{40.76b}$$

For the case of binomially distributed n successes out of N trials with probability of success p, the upper and lower limits on p are found to be

$$p_{\rm lo} = \frac{n F_F^{-1}[\alpha_{\rm lo}; 2n, 2(N-n+1)]}{N-n+1 \ + \ n F_F^{-1}[\alpha_{\rm lo}; 2n, 2(N-n+1)]} \ , \tag{40.77a}$$

$$p_{\rm up} = \frac{(n+1) F_F^{-1}[1-\alpha_{\rm up}; 2(n+1), 2(N-n)]}{(N-n) \ + \ (n+1) F_F^{-1}[1-\alpha_{\rm up}; 2(n+1), 2(N-n)]} \ . \tag{40.77b}$$

Here F_F^{-1} is the quantile of the F distribution (also called the Fisher–Snedecor distribution; see Ref. [4]).

Several problems with such intervals are overcome by using the unified approach of Feldman and Cousins [40]. Properties of these intervals are described further in the *Review*. Table 40.4 gives the unified confidence

Table 40.3: Lower and upper (one-sided) limits for the mean μ of a Poisson variable given n observed events in the absence of background, for confidence levels of 90% and 95%.

	$1-\alpha=90\%$		$1-\alpha=95\%$	
n	$\mu_{\rm lo}$	$\mu_{\rm up}$	$\mu_{\rm lo}$	$\mu_{\rm up}$
0	–	2.30	–	3.00
1	0.105	3.89	0.051	4.74
2	0.532	5.32	0.355	6.30
3	1.10	6.68	0.818	7.75
4	1.74	7.99	1.37	9.15
5	2.43	9.27	1.97	10.51
6	3.15	10.53	2.61	11.84
7	3.89	11.77	3.29	13.15
8	4.66	12.99	3.98	14.43
9	5.43	14.21	4.70	15.71
10	6.22	15.41	5.43	16.96

intervals $[\mu_1, \mu_2]$ for the mean of a Poisson variable given n observed events in the absence of background, for confidence levels of 90% and 95%.

Table 40.4: Unified confidence intervals $[\mu_1, \mu_2]$ for a the mean of a Poisson variable given n observed events in the absence of background, for confidence levels of 90% and 95%.

	$1-\alpha=90\%$		$1-\alpha=95\%$	
n	μ_1	μ_2	μ_1	μ_2
0	0.00	2.44	0.00	3.09
1	0.11	4.36	0.05	5.14
2	0.53	5.91	0.36	6.72
3	1.10	7.42	0.82	8.25
4	1.47	8.60	1.37	9.76
5	1.84	9.99	1.84	11.26
6	2.21	11.47	2.21	12.75
7	3.56	12.53	2.58	13.81
8	3.96	13.99	2.94	15.29
9	4.36	15.30	4.36	16.77
10	5.50	16.50	4.75	17.82

Further discussion and all references may be found in the full *Review of Particle Physics*.

44. Monte Carlo Particle Numbering Scheme

Revised May 2020 by F. Krauss (Durham U.), S. Navas (Granada U.), P. Richardson (Durham U.) and T. Sjöstrand (Lund U.).

The Monte Carlo particle numbering scheme presented here is intended to facilitate interfacing between event generators, detector simulators, and analysis packages used in particle physics. The numbering scheme is used in several event generators, *e.g.* HERWIG, PYTHIA, and SHERPA, and interfaces, *e.g.* `/HEPEVT/` and HepMC. The general form is a 7–digit number:

$$\pm n\; n_r\; n_L\; n_{q_1}\; n_{q_2}\; n_{q_3}\; n_J\ .$$

This encodes information about the particle's spin, flavor content, and internal quantum numbers: See the full review for details. An *abbreviated* list of common or well-measured particles follows below.

QUARKS	
d	1
u	2
s	3
c	4
b	5
t	6
b'	7
t'	8

LEPTONS	
e^-	11
ν_e	12
μ^-	13
ν_μ	14
τ^-	15
ν_τ	16
τ'^-	17
$\nu_{\tau'}$	18

GAUGE AND HIGGS BOSONS	
g	(9) 21
γ	22
Z^0	23
W^+	24
h^0/H_1^0	25
Z'/Z_2^0	32
Z''/Z_3^0	33
W'/W_2^+	34
H^0/H_2^0	35
A^0/H_3^0	36
H^+	37
H^{++}	38
a^0/H_4^0	40

SPECIAL PARTICLES	
G (graviton)	39
R^0	41
LQ^c	42
DM ($S=0$)	51
DM ($S=\frac{1}{2}$)	52
DM ($S=1$)	53
reggeon	110
pomeron	990
odderon	9990
for MC internal use 81–100, 901–930, 998–999, 1901–1930, 2901–2930, and 3901–3930	

SUSY PARTICLES	
$\tilde{d}_L$	1000001
$\tilde{u}_L$	1000002
$\tilde{s}_L$	1000003
$\tilde{c}_L$	1000004
$\tilde{b}_1$	1000005
$\tilde{t}_1$	1000006
$\tilde{e}_L^-$	1000011
$\tilde{\nu}_{eL}$	1000012
$\tilde{\mu}_L^-$	1000013
$\tilde{\nu}_{\mu L}$	1000014
$\tilde{\tau}_1^-$	1000015
$\tilde{\nu}_{\tau L}$	1000016
$\tilde{d}_R$	2000001
$\tilde{u}_R$	2000002
$\tilde{s}_R$	2000003
$\tilde{c}_R$	2000004
$\tilde{b}_2$	2000005
$\tilde{t}_2$	2000006
$\tilde{e}_R^-$	2000011
$\tilde{\mu}_R^-$	2000013
$\tilde{\tau}_2^-$	2000015
$\tilde{g}$	1000021
$\tilde{\chi}_1^0$	1000022
$\tilde{\chi}_2^0$	1000023
$\tilde{\chi}_1^+$	1000024
$\tilde{\chi}_3^0$	1000025
$\tilde{\chi}_4^0$	1000035
$\tilde{\chi}_2^+$	1000037
$\tilde{G}$	1000039

DIQUARKS	
$(dd)_1$	1103
$(ud)_0$	2101
$(ud)_1$	2103
$(uu)_1$	2203
$(sd)_0$	3101
$(sd)_1$	3103
$(su)_0$	3201
$(su)_1$	3203
$(ss)_1$	3303

LIGHT $I=1$ MESONS	
π^0	111
π^+	211
$a_0(980)^0$	9000111
$a_0(980)^+$	9000211
$a_0(1450)^0$	10111
$a_0(1450)^+$	10211
$\rho(770)^0$	113
$\rho(770)^+$	213
$b_1(1235)^0$	10113
$b_1(1235)^+$	10213
$a_2(1320)^0$	115
$a_2(1320)^+$	215
$\rho_3(1690)^0$	117
$\rho_3(1690)^+$	217
$a_4(2040)^0$	119
$a_4(2040)^+$	219

LIGHT $I=0$ MESONS ($u\bar{u}$, $d\bar{d}$, $s\bar{s}$ admixtures)	
η	221
$\eta'(958)$	331
$f_0(500)$	9000221
$f_0(980)$	9010221
$\omega(782)$	223
$\phi(1020)$	333
$f_1(1285)$	20223
$f_2(1270)$	225
$f_2'(1525)$	335
$\omega_3(1670)$	227
$\phi_3(1850)$	337
$f_4(2050)$	229

STRANGE MESONS	
K_L^0	130
K_S^0	310
K^0	311
K^+	321
$K_0^*(1430)^0$	10311
$K_0^*(1430)^+$	10321
$K^*(892)^0$	313
$K^*(892)^+$	323
$K_1(1270)^0$	10313
$K_1(1270)^+$	10323
$K^*(1680)^0$	30313
$K^*(1680)^+$	30323
$K_2^*(1430)^0$	315
$K_2^*(1430)^+$	325
$K_2(1770)^0$	10315
$K_2(1770)^+$	10325
$K_3^*(1780)^0$	317
$K_3^*(1780)^+$	327
$K_4^*(2045)^0$	319
$K_4^*(2045)^+$	329

CHARMED MESONS	
D^+	411
D^0	421
$D_0^*(2400)^+$	10411
$D_0^*(2400)^0$	10421
$D^*(2010)^+$	413
$D^*(2007)^0$	423
$D_1(2420)^+$	10413
$D_1(2420)^0$	10423
$D_1(H)^+$	20413
$D_1(2430)^0$	20423
$D_2^*(2460)^+$	415
$D_2^*(2460)^0$	425
D_s^+	431
$D_{s0}^*(2317)^+$	10431
D_s^{*+}	433
$D_{s1}(2536)^+$	10433
$D_{s1}(2460)^+$	20433
$D_{s2}^*(2573)^+$	435

BOTTOM MESONS	
B^0	511
B^+	521
B_0^{*0}	10511
B_0^{*+}	10521
B^{*0}	513
B^{*+}	523
$B_1(L)^0$	10513
$B_1(L)^+$	10523
$B_1(H)^0$	20513
$B_1(H)^+$	20523
B_2^{*0}	515
B_2^{*+}	525
B_s^0	531
B_s^{*0}	533
B_{s2}^{*0}	535
B_c^+	541
B_c^{*+}	543
B_{c2}^{*+}	545

$c\bar{c}$ MESONS	
$\eta_c(1S)$	441
$\chi_{c0}(1P)$	10441
$\eta_c(2S)$	100441
$J/\psi(1S)$	443
$h_c(1P)$	10443
$\chi_{c1}(1P)$	20443
$\psi(2S)$	100443
$\psi(3770)$	30443
$\chi_{c2}(1P)$	445

$b\bar{b}$ MESONS	
$\eta_b(1S)$	551
$\chi_{b0}(1P)$	10551
$\chi_{b0}(2P)$	110551
$\Upsilon(1S)$	553
$h_b(1P)$	10553
$\chi_{b1}(1P)$	20553
$\Upsilon_1(1D)$	30553
$\Upsilon(2S)$	100553
$h_b(2P)$	110553
$\chi_{b1}(2P)$	120553
$\Upsilon(3S)$	200553
$\Upsilon(4S)$	300553
$\Upsilon(10860)$	9000553
$\Upsilon(11020)$	9010553
$\chi_{b2}(1P)$	555
$\Upsilon_2(1D)$	20555
$\chi_{b2}(2P)$	100555

LIGHT BARYONS	
p	2212
n	2112
Δ^{++}	2224
Δ^+	2214
Δ^0	2114
Δ^-	1114

STRANGE BARYONS	
Λ	3122
Σ^+	3222
Σ^0	3212
Σ^-	3112
Σ^{*+}	3224
Σ^{*0}	3214
Σ^{*-}	3114
Ξ^0	3322
Ξ^-	3312
Ξ^{*0}	3324
Ξ^{*-}	3314
Ω^-	3334

CHARMED BARYONS	
Λ_c^+	4122
Σ_c^{++}	4222
Σ_c^+	4212
Σ_c^0	4112
Σ_c^{*++}	4224
Σ_c^{*+}	4214
Σ_c^{*0}	4114
Ξ_c^+	4232
Ξ_c^0	4132
$\Xi_c'^+$	4322
$\Xi_c'^0$	4312
Ξ_c^{*+}	4324
Ξ_c^{*0}	4314
Ω_c^0	4332
Ω_c^{*0}	4334
Ξ_{cc}^{++}	4422

BOTTOM BARYONS	
Λ_b^0	5122
Σ_b^-	5112
Σ_b^0	5212
Σ_b^+	5222
Σ_b^{*-}	5114
Σ_b^{*0}	5214
Σ_b^{*+}	5224
Ξ_b^-	5132
Ξ_b^0	5232
$\Xi_b'^-$	5312
$\Xi_b'^0$	5322
Ξ_b^{*-}	5314
Ξ_b^{*0}	5324
Ω_b^-	5332
Ω_b^{*-}	5334

PENTA-QUARKS	
Θ^+	9221132
Φ^{--}	9331122

45. Clebsch-Gordan Coefficients, Spherical Harmonics, and *d* Functions

Note: A square-root sign is to be understood over *every* coefficient, *e.g.*, for −8/15 read $-\sqrt{8/15}$.

Notation:

		J	*J*	...
		M	M	...
m_1	m_2	Coefficients		
m_1	m_2			
.	.			

$$Y_1^0 = \sqrt{\frac{3}{4\pi}}\cos\theta$$

$$Y_1^1 = -\sqrt{\frac{3}{8\pi}}\sin\theta\, e^{i\phi}$$

$$Y_2^0 = \sqrt{\frac{5}{4\pi}}\Big(\frac{3}{2}\cos^2\theta - \frac{1}{2}\Big)$$

$$Y_2^1 = -\sqrt{\frac{15}{8\pi}}\sin\theta\cos\theta\, e^{i\phi}$$

$$Y_2^2 = \frac{1}{4}\sqrt{\frac{15}{2\pi}}\sin^2\theta\, e^{2i\phi}$$

$$Y_\ell^{-m} = (-1)^m Y_\ell^{m*}$$

$$\langle j_1 j_2 m_1 m_2 | j_1 j_2 J M\rangle = (-1)^{J-j_1-j_2}\langle j_2 j_1 m_2 m_1 | j_2 j_1 J M\rangle$$

1/2×1/2

		1
		+1
+1/2	+1/2	1

		1	0
		0	0
+1/2	−1/2	1/2	1/2
−1/2	+1/2	1/2	−1/2

		1
		−1
−1/2	−1/2	1

1×1/2

		3/2
		+3/2
+1	+1/2	1

		3/2	1/2
		+1/2	+1/2
+1	−1/2	1/3	2/3
0	+1/2	2/3	−1/3

		3/2	1/2
		−1/2	−1/2
0	−1/2	2/3	1/3
−1	+1/2	1/3	−2/3

		3/2
		−3/2
−1	−1/2	1

2×1

		3
		+3
+2	+1	1

		3	2
		+2	+2
+2	0	1/3	2/3
+1	+1	2/3	−1/3

		3	2	1
		+1	+1	+1
+2	−1	1/15	1/3	3/5
+1	0	8/15	1/6	−3/10
0	+1	2/5	−1/2	1/10

		3	2	1
		0	0	0
+1	−1	1/5	1/2	3/10
0	0	3/5	0	−2/5
−1	+1	1/5	−1/2	3/10

		3	2	1
		−1	−1	−1
0	−1	2/5	1/2	1/10
−1	0	8/15	−1/6	−3/10
−2	+1	1/15	−1/3	3/5

		3	2
		−2	−2
−1	−1	2/3	1/3
−2	0	1/3	−2/3

		3
		−3
−2	−1	1

1×1

		2
		+2
+1	+1	1

		2	1
		+1	+1
+1	0	1/2	1/2
0	+1	1/2	−1/2

		2	1	0
		0	0	0
+1	−1	1/6	1/2	1/3
0	0	2/3	0	−1/3
−1	+1	1/6	−1/2	1/3

		2	1
		−1	−1
0	−1	1/2	1/2
−1	0	1/2	−1/2

		2
		−2
−1	−1	1

3/2×1

		5/2
		+5/2
+3/2	+1	1

		5/2	3/2
		+3/2	+3/2
+3/2	0	2/5	3/5
+1/2	+1	3/5	−2/5

		5/2	3/2	1/2
		+1/2	+1/2	+1/2
+3/2	−1	1/10	2/5	1/2
+1/2	0	3/5	1/15	−1/3
−1/2	+1	3/10	−8/15	1/6

		5/2	3/2	1/2
		−1/2	−1/2	−1/2
+1/2	−1	3/10	8/15	1/6
−1/2	0	3/5	−1/15	−1/3
−3/2	+1	1/10	−2/5	1/2

		5/2	3/2
		−3/2	−3/2
−1/2	−1	3/5	2/5
−3/2	0	2/5	−3/5

		5/2
		−5/2
−3/2	−1	1

2×1/2

		5/2
		+5/2
+2	+1/2	1

		5/2	3/2
		+3/2	+3/2
+2	−1/2	1/5	4/5
+1	+1/2	4/5	−1/5

		5/2	3/2
		+1/2	+1/2
+1	−1/2	2/5	3/5
0	+1/2	3/5	−2/5

		5/2	3/2
		−1/2	−1/2
0	−1/2	3/5	2/5
−1	+1/2	2/5	−3/5

		5/2	3/2
		−3/2	−3/2
−1	−1/2	4/5	1/5
−2	+1/2	1/5	−4/5

		5/2
		−5/2
−2	−1/2	1

3/2×1/2

		2
		+2
+3/2	+1/2	1

		2	1
		+1	+1
+3/2	−1/2	1/4	3/4
+1/2	+1/2	3/4	−1/4

		2	1
		0	0
+1/2	−1/2	1/2	1/2
−1/2	+1/2	1/2	−1/2

		2	1
		−1	−1
−1/2	−1/2	3/4	1/4
−3/2	+1/2	1/4	−3/4

		2
		−2
−3/2	−1/2	1

$$d^{\ell}_{m,0} = \sqrt{\frac{4\pi}{2\ell+1}}\, Y^m_\ell\, e^{-im\phi}$$

$$d^j_{m',m} = (-1)^{m-m'} d^j_{m,m'} = d^j_{-m,-m'}$$

$$d^{1}_{0,0} = \cos\theta \qquad d^{1/2}_{1/2,1/2} = \cos\frac{\theta}{2} \qquad d^{1/2}_{1/2,-1/2} = -\sin\frac{\theta}{2}$$

$$d^{1}_{1,1} = \frac{1+\cos\theta}{2} \qquad d^{1}_{1,0} = -\frac{\sin\theta}{\sqrt{2}} \qquad d^{1}_{1,-1} = \frac{1-\cos\theta}{2}$$

2×3/2

		7/2
		+7/2
+2	+3/2	1

		7/2	5/2
		+5/2	+5/2
+2	+1/2	3/7	4/7
+1	+3/2	4/7	−3/7

		7/2	5/2	3/2
		+3/2	+3/2	+3/2
+2	−1/2	1/7	16/35	2/5
+1	+1/2	4/7	1/35	−2/5
0	+3/2	2/7	−18/35	1/5

		7/2	5/2	3/2	1/2
		+1/2	+1/2	+1/2	+1/2
+2	−3/2	1/35	6/35	2/5	2/5
+1	−1/2	12/35	5/14	0	−3/10
0	+1/2	18/35	−3/35	−1/5	1/5
−1	+3/2	4/35	−27/70	2/5	−1/10

		7/2	5/2	3/2	1/2
		−1/2	−1/2	−1/2	−1/2
+1	−3/2	4/35	27/70	2/5	1/10
0	−1/2	18/35	3/35	−1/5	−1/5
−1	+1/2	12/35	−5/14	0	3/10
−2	+3/2	1/35	−6/35	2/5	−2/5

		7/2	5/2	3/2
		−3/2	−3/2	−3/2
0	−3/2	2/7	18/35	1/5
−1	−1/2	4/7	−1/35	−2/5
−2	+1/2	1/7	−16/35	2/5

		7/2	5/2
		−5/2	−5/2
−1	−3/2	4/7	3/7
−2	−1/2	3/7	−4/7

		7/2
		−7/2
−2	−3/2	1

3/2×3/2

		3
		+3
+3/2	+3/2	1

		3	2
		+2	+2
+3/2	+1/2	1/2	1/2
+1/2	+3/2	1/2	−1/2

		3	2	1
		+1	+1	+1
+3/2	−1/2	1/5	1/2	3/10
+1/2	+1/2	3/5	0	−2/5
−1/2	+3/2	1/5	−1/2	3/10

		3	2	1	0
		0	0	0	0
+3/2	−3/2	1/20	1/4	9/20	1/4
+1/2	−1/2	9/20	1/4	−1/20	−1/4
−1/2	+1/2	9/20	−1/4	−1/20	1/4
−3/2	+3/2	1/20	−1/4	9/20	−1/4

		3	2	1
		−1	−1	−1
+1/2	−3/2	1/5	1/2	3/10
−1/2	−1/2	3/5	0	−2/5
−3/2	+1/2	1/5	−1/2	3/10

		3	2
		−2	−2
−1/2	−3/2	1/2	1/2
−3/2	−1/2	1/2	−1/2

		3
		−3
−3/2	−3/2	1

2×2

		4
		+4
+2	+2	1

		4	3
		+3	+3
+2	+1	1/2	1/2
+1	+2	1/2	−1/2

		4	3	2
		+2	+2	+2
+2	0	3/14	1/2	2/7
+1	+1	4/7	0	−3/7
0	+2	3/14	−1/2	2/7

		4	3	2	1
		+1	+1	+1	+1
+2	−1	1/14	3/10	3/7	1/5
+1	0	3/7	1/5	−1/14	−3/10
0	+1	3/7	−1/5	−1/14	3/10
−1	+2	1/14	−3/10	3/7	−1/5

		4	3	2	1	0
		0	0	0	0	0
+2	−2	1/70	1/10	2/7	2/5	1/5
+1	−1	8/35	2/5	1/14	−1/10	−1/5
0	0	18/35	0	−2/7	0	1/5
−1	+1	8/35	−2/5	1/14	1/10	−1/5
−2	+2	1/70	−1/10	2/7	−2/5	1/5

		4	3	2	1
		−1	−1	−1	−1
+1	−2	1/14	3/10	3/7	1/5
0	−1	3/7	1/5	−1/14	−3/10
−1	0	3/7	−1/5	−1/14	3/10
−2	+1	1/14	−3/10	3/7	−1/5

		4	3	2
		−2	−2	−2
0	−2	3/14	1/2	2/7
−1	−1	4/7	0	−3/7
−2	0	3/14	−1/2	2/7

		4	3
		−3	−3
−1	−2	1/2	1/2
−2	−1	1/2	−1/2

		4
		−4
−2	−2	1

$$d^{3/2}_{3/2,3/2} = \frac{1+\cos\theta}{2}\cos\frac{\theta}{2}$$

$$d^{3/2}_{3/2,1/2} = -\sqrt{3}\frac{1+\cos\theta}{2}\sin\frac{\theta}{2}$$

$$d^{3/2}_{3/2,-1/2} = \sqrt{3}\frac{1-\cos\theta}{2}\cos\frac{\theta}{2}$$

$$d^{3/2}_{3/2,-3/2} = -\frac{1-\cos\theta}{2}\sin\frac{\theta}{2}$$

$$d^{3/2}_{1/2,1/2} = \frac{3\cos\theta-1}{2}\cos\frac{\theta}{2}$$

$$d^{3/2}_{1/2,-1/2} = -\frac{3\cos\theta+1}{2}\sin\frac{\theta}{2}$$

$$d^{2}_{2,2} = \left(\frac{1+\cos\theta}{2}\right)^2$$

$$d^{2}_{2,1} = -\frac{1+\cos\theta}{2}\sin\theta$$

$$d^{2}_{2,0} = \frac{\sqrt{6}}{4}\sin^2\theta$$

$$d^{2}_{2,-1} = -\frac{1-\cos\theta}{2}\sin\theta$$

$$d^{2}_{2,-2} = \left(\frac{1-\cos\theta}{2}\right)^2$$

$$d^{2}_{1,1} = \frac{1+\cos\theta}{2}(2\cos\theta-1)$$

$$d^{2}_{1,0} = -\sqrt{\frac{3}{2}}\sin\theta\cos\theta$$

$$d^{2}_{1,-1} = \frac{1-\cos\theta}{2}(2\cos\theta+1)$$

$$d^{2}_{0,0} = \left(\frac{3}{2}\cos^2\theta-\frac{1}{2}\right)$$

48. Kinematics

Revised August 2019 by D.J. Miller (Glasgow U.) and D.R. Tovey (Sheffield U.).

Throughout this section units are used in which $\hbar = c = 1$. The following conversions are useful: $\hbar c = 197.3$ MeV fm, $(\hbar c)^2 = 0.3894$ (GeV)^2 mb.

48.1. Lorentz transformations

The energy E and 3-momentum $\boldsymbol{p}$ of a particle of mass m form a 4-vector $p = (E, \boldsymbol{p})$ whose square $p^2 \equiv E^2 - |\boldsymbol{p}|^2 = m^2$. The velocity of the particle is $\boldsymbol{\beta} = \boldsymbol{p}/E$. The energy and momentum $(E^*, \boldsymbol{p}^*)$ viewed from a frame moving with velocity $\boldsymbol{\beta}_f$ are given by

$$\begin{pmatrix} E^* \\ p^*_\parallel \end{pmatrix} = \begin{pmatrix} \gamma_f & -\gamma_f\beta_f \\ -\gamma_f\beta_f & \gamma_f \end{pmatrix} \begin{pmatrix} E \\ p_\parallel \end{pmatrix} , \qquad p^*_T = p_T , \tag{48.1}$$

where $\gamma_f = (1-\beta_f^2)^{-1/2}$ and p_T $(p_\parallel)$ are the components of $\boldsymbol{p}$ perpendicular (parallel) to $\boldsymbol{\beta}_f$. Other 4-vectors, such as the space-time coordinates of events, of course transform in the same way. The scalar product of two 4-momenta $p_1 \cdot p_2 = E_1 E_2 - \boldsymbol{p}_1 \cdot \boldsymbol{p}_2$ is invariant (frame independent).

48.2. Center-of-mass energy and momentum

In the collision of two particles of masses m_1 and m_2 the total center-of-mass energy can be expressed in the Lorentz-invariant form

$$\begin{aligned} E_{\rm cm} &= \left[(E_1 + E_2)^2 - (\boldsymbol{p}_1 + \boldsymbol{p}_2)^2\right]^{1/2} , \\ &= \left[m_1^2 + m_2^2 + 2E_1E_2(1 - \beta_1\beta_2\cos\theta)\right]^{1/2} , \end{aligned} \tag{48.2}$$

where θ is the angle between the particles. In the frame where one particle (of mass m_2) is at rest (lab frame),

$$E_{\rm cm} = (m_1^2 + m_2^2 + 2E_{1\,\rm lab}\, m_2)^{1/2} . \tag{48.3}$$

The velocity of the center-of-mass in the lab frame is

$$\boldsymbol{\beta}_{\rm cm} = \boldsymbol{p}_{\rm lab}/(E_{1\,\rm lab} + m_2) , \tag{48.4}$$

where $\boldsymbol{p}_{\rm lab} \equiv \boldsymbol{p}_{1\,\rm lab}$ and

$$\gamma_{\rm cm} = (E_{1\,\rm lab} + m_2)/E_{\rm cm} . \tag{48.5}$$

The c.m. momenta of particles 1 and 2 are of magnitude

$$p_{\rm cm} = p_{\rm lab}\frac{m_2}{E_{\rm cm}} . \tag{48.6}$$

For example, if a 0.80 GeV/c kaon beam is incident on a proton target, the center of mass energy is 1.699 GeV and the center of mass momentum of either particle is 0.442 GeV/c. It is also useful to note that

$$E_{\rm cm}\, dE_{\rm cm} = m_2\, dE_{1\,\rm lab} = m_2\, \beta_{1\,\rm lab}\, dp_{\rm lab} . \tag{48.7}$$

48.3. Lorentz-invariant amplitudes

The matrix elements for a scattering or decay process are written in terms of an invariant amplitude $-i\mathscr{M}$. As an example, the S-matrix for $2 \to 2$ scattering is related to $\mathscr{M}$ by

$$\begin{aligned} \langle p_1' p_2' \,|S|\, p_1 p_2\rangle &= I - i(2\pi)^4\, \delta^4(p_1 + p_2 - p_1' - p_2') \\ &\quad \times \frac{\mathscr{M}(p_1,\, p_2;\; p_1',\, p_2')}{(2E_1)^{1/2}\,(2E_2)^{1/2}\,(2E_1')^{1/2}\,(2E_2')^{1/2}} . \end{aligned} \tag{48.8}$$

The state normalization is such that

$$\langle p'|p\rangle = (2\pi)^3\delta^3(\boldsymbol{p}-\boldsymbol{p}') \ . \tag{48.9}$$

48.4. Particle decays

The partial decay rate of a particle of mass M into n bodies in its rest frame is given in terms of the Lorentz-invariant matrix element $\mathscr{M}$ by

$$d\Gamma = \frac{(2\pi)^4}{2M}\,|\mathscr{M}|^2\,d\Phi_n\,(P;\,p_1,\,\ldots,\,p_n), \tag{48.11}$$

where $d\Phi_n$ is an element of n-body phase space given by

$$d\Phi_n(P;\,p_1,\,\ldots,\,p_n) = \delta^4\,(P-\sum_{i=1}^{n} p_i)\,\prod_{i=1}^{n}\frac{d^3p_i}{(2\pi)^3 2E_i} \ . \tag{48.12}$$

This phase space can be generated recursively, viz.

$$d\Phi_n(P;\,p_1,\,\ldots,\,p_n) = d\Phi_j(q;\,p_1,\,\ldots,\,p_j)$$
$$\times\ d\Phi_{n-j+1}\,(P;\,q,\,p_{j+1},\,\ldots,\,p_n)(2\pi)^3 dq^2\ , \tag{48.13}$$

where $q^2 = (\sum_{i=1}^{j} E_i)^2 - \left|\sum_{i=1}^{j} \boldsymbol{p}_i\right|^2$. This form is particularly useful in the case where a particle decays into another particle that subsequently decays.

48.4.1. ***Survival probability*** : If a particle of mass M has mean proper lifetime τ $(=1/\Gamma)$ and has momentum $(E,\boldsymbol{p})$, then the probability that it lives for a time t_0 or greater before decaying is given by

$$P(t_0) = e^{-t_0\,\Gamma/\gamma} = e^{-Mt_0\,\Gamma/E}\ , \tag{48.14}$$

and the probability that it travels a distance x_0 or greater is

$$P(x_0) = e^{-Mx_0\,\Gamma/|\boldsymbol{p}|}\ . \tag{48.15}$$

48.4.2. ***Two-body decays*** :

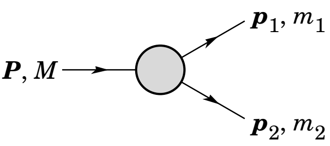


Figure 48.1: Definitions of variables for two-body decays.

In the rest frame of a particle of mass M, decaying into 2 particles labeled 1 and 2,

$$E_1 = \frac{M^2 - m_2^2 + m_1^2}{2M}\ , \tag{48.16}$$

$$|\boldsymbol{p}_1| = |\boldsymbol{p}_2|$$
$$= \frac{\left[\left(M^2-(m_1+m_2)^2\right)\left(M^2-(m_1-m_2)^2\right)\right]^{1/2}}{2M}\ , \tag{48.17}$$

and

$$d\Gamma = \frac{1}{32\pi^2}\,|\mathscr{M}|^2\,\frac{|\boldsymbol{p}_1|}{M^2}\,d\Omega\ , \tag{48.18}$$

where $d\Omega = d\phi_1 d(\cos\theta_1)$ is the solid angle of particle 1. The invariant mass M can be determined from the energies and momenta using Eq. (48.2) with $M = E_{\rm cm}$.

48.4.3. ***Three-body decays*** :

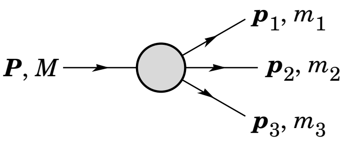


Figure 48.2: Definitions of variables for three-body decays.

Defining $p_{ij} = p_i + p_j$ and $m_{ij}^2 = p_{ij}^2$, then $m_{12}^2 + m_{23}^2 + m_{13}^2 = M^2 + m_1^2 + m_2^2 + m_3^2$ and $m_{12}^2 = (P - p_3)^2 = M^2 + m_3^2 - 2ME_3$, where E_3 is the energy of particle 3 in the rest frame of M. In that frame, the momenta of the three decay particles lie in a plane. The relative orientation of these three momenta is fixed if their energies are known. The momenta can therefore be specified in space by giving three Euler angles (α, β, γ) that specify the orientation of the final system relative to the initial particle. The direction of any one of the particles relative to the frame in which the initial particle is described can be specified in space by two angles (α, β) while a third angle, γ, can be set as the azimuthal angle of a second particle around the first [1]. Then

$$d\Gamma = \frac{1}{(2\pi)^5} \frac{1}{16M} \, |\mathscr{M}|^2 \, dE_1 \, dE_3 \, d\alpha \, d(\cos\beta) \, d\gamma \ . \tag{48.19}$$

Alternatively

$$d\Gamma = \frac{1}{(2\pi)^5} \frac{1}{16M^2} \, |\mathscr{M}|^2 \, |\boldsymbol{p}_1^*| \, |\boldsymbol{p}_3| \, dm_{12} \, d\Omega_1^* \, d\Omega_3 \ , \tag{48.20}$$

where $(|\boldsymbol{p}_1^*|, \ \Omega_1^*)$ is the momentum of particle 1 in the rest frame of 1 and 2, and Ω_3 is the angle of particle 3 in the rest frame of the decaying particle. $|\boldsymbol{p}_1^*|$ and $|\boldsymbol{p}_3|$ are given by

$$|\boldsymbol{p}_1^*| = \frac{\left[\left(m_{12}^2 - (m_1 + m_2)^2\right)\left(m_{12}^2 - (m_1 - m_2)^2\right)\right]^{1/2}}{2m_{12}} \ , \tag{48.21a}$$

and

$$|\boldsymbol{p}_3| = \frac{\left[\left(M^2 - (m_{12} + m_3)^2\right)\left(M^2 - (m_{12} - m_3)^2\right)\right]^{1/2}}{2M} \ . \tag{48.21b}$$

[Compare with Eq. (48.17).]

If the decaying particle is a scalar or we average over its spin states, then integration over the angles in Eq. (48.19) gives

$$\begin{aligned} d\Gamma &= \frac{1}{(2\pi)^3} \frac{1}{8M} \, \overline{|\mathscr{M}|^2} \, dE_1 \, dE_3 \\ &= \frac{1}{(2\pi)^3} \frac{1}{32M^3} \, \overline{|\mathscr{M}|^2} \, dm_{12}^2 \, dm_{23}^2 \ . \end{aligned} \tag{48.22}$$

This is the standard form for the Dalitz plot.

48.4.3.1. *Dalitz plot:* For a given value of m_{12}^2, the range of m_{23}^2 is determined by its values when $\boldsymbol{p}_2$ is parallel or antiparallel to $\boldsymbol{p}_3$:

$$(m_{23}^2)_{\rm max} =$$
$$(E_2^* + E_3^*)^2 - \left(\sqrt{E_2^{*2} - m_2^2} - \sqrt{E_3^{*2} - m_3^2}\right)^2 , \qquad (48.23a)$$
$$(m_{23}^2)_{\rm min} =$$
$$(E_2^* + E_3^*)^2 - \left(\sqrt{E_2^{*2} - m_2^2} + \sqrt{E_3^{*2} - m_3^2}\right)^2 . \qquad (48.23b)$$

Here $E_2^* = (m_{12}^2 - m_1^2 + m_2^2)/2m_{12}$ and $E_3^* = (M^2 - m_{12}^2 - m_3^2)/2m_{12}$ are the energies of particles 2 and 3 in the m_{12} rest frame. The scatter plot in m_{12}^2 and m_{23}^2 is called a Dalitz plot. If $\overline{|\mathscr{M}|^2}$ is constant, the allowed region of the plot will be uniformly populated with events [see Eq. (48.22)]. A nonuniformity in the plot gives immediate information on $|\mathscr{M}|^2$. For example, in the case of $D \to K\pi\pi$, bands appear when $m_{(K\pi)} = m_{K^*(892)}$, reflecting the appearance of the decay chain $D \to K^*(892)\pi \to K\pi\pi$.

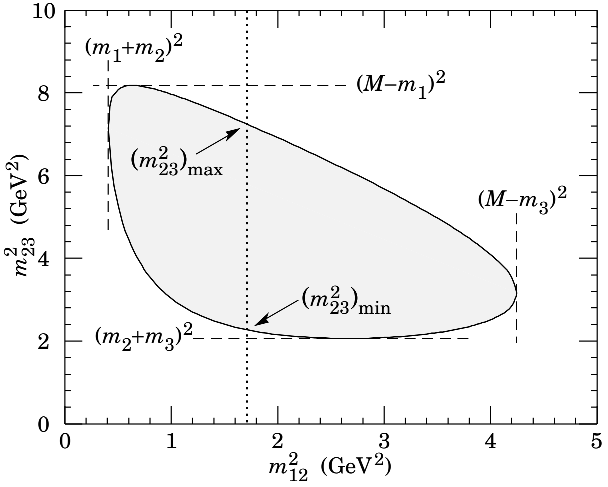


Figure 48.3: Dalitz plot for a three-body final state. In this example, the state is $\pi^+\overline{K}^0p$ at 3 GeV. Four-momentum conservation restricts events to the shaded region.

48.4.4. *Kinematic limits* :

48.4.4.1. *Three-body decays:* In a three-body decay (Fig. 48.2) the maximum of $|\boldsymbol{p}_3|$, [given by Eq. (48.21)], is achieved when $m_{12} = m_1 + m_2$, *i.e.*, particles 1 and 2 have the same vector velocity in the rest frame of the decaying particle. If, in addition, $m_3 > m_1, m_2$, then $|\boldsymbol{p}_3|_{\rm max} > |\boldsymbol{p}_1|_{\rm max}$, $|\boldsymbol{p}_2|_{\rm max}$. The distribution of m_{12} values possesses an end-point or maximum value at $m_{12} = M - m_3$. This can be used to constrain the mass difference of a parent particle and one invisible decay product.

48.4.5. *Multibody decays* : The above results may be generalized to final states containing any number of particles by combining some of the particles into "effective particles" and treating the final states as 2 or 3 "effective particle" states. Thus, if $p_{ijk\ldots} = p_i + p_j + p_k + \ldots$, then

$$m_{ijk\ldots} = \sqrt{p^2{}_{ijk\ldots}} \;, \tag{48.26}$$

and $m_{ijk\ldots}$ may be used in place of *e.g.*, m_{12} in the relations in Sec. 48.4.3 or Sec. 48.4.4 above.

48.5. Cross sections

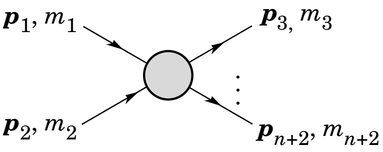


Figure 48.5: Definitions of variables for production of an n-body final state.

The differential cross section is given by

$$d\sigma = \frac{(2\pi)^4|\mathscr{M}|^2}{4\sqrt{(p_1\cdot p_2)^2 - m_1^2 m_2^2}} \times \; d\Phi_n(p_1+p_2;\; p_3, \,\ldots, \, p_{n+2}) \;. \tag{48.27}$$

[See Eq. (48.12).] In the rest frame of m_2(lab),

$$\sqrt{(p_1\cdot p_2)^2 - m_1^2 m_2^2} = m_2 p_{1\,\text{lab}} \;; \tag{48.28a}$$

while in the center-of-mass frame

$$\sqrt{(p_1\cdot p_2)^2 - m_1^2 m_2^2} = p_{1\text{cm}}\sqrt{s} \;. \tag{48.28b}$$

48.5.1. *Two-body reactions* :

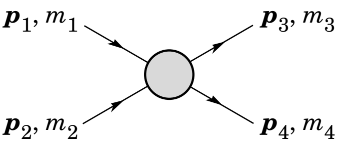


Figure 48.6: Definitions of variables for a two-body final state.

Two particles of momenta p_1 and p_2 and masses m_1 and m_2 scatter to particles of momenta p_3 and p_4 and masses m_3 and m_4; the Lorentz-invariant Mandelstam variables are defined by

$$\begin{aligned} s &= (p_1+p_2)^2 = (p_3+p_4)^2 \\ &= m_1^2 + 2E_1E_2 - 2\boldsymbol{p}_1\cdot\boldsymbol{p}_2 + m_2^2 \;, \end{aligned} \tag{48.29}$$

$$\begin{aligned} t &= (p_1-p_3)^2 = (p_2-p_4)^2 \\ &= m_1^2 - 2E_1E_3 + 2\boldsymbol{p}_1\cdot\boldsymbol{p}_3 + m_3^2 \;, \end{aligned} \tag{48.30}$$

$$u = (p_1 - p_4)^2 = (p_2 - p_3)^2$$
$$= m_1^2 - 2E_1E_4 + 2\boldsymbol{p}_1 \cdot \boldsymbol{p}_4 + m_4^2 \ , \qquad (48.31)$$

and they satisfy

$$s + t + u = m_1^2 + m_2^2 + m_3^2 + m_4^2 \ . \qquad (48.32)$$

The two-body cross section may be written as

$$\frac{d\sigma}{dt} = \frac{1}{64\pi s}\,\frac{1}{|\boldsymbol{p}_{1\text{cm}}|^2}\,|\mathscr{M}|^2 \ . \qquad (48.33)$$

In the center-of-mass frame

$$t = (E_{1\text{cm}} - E_{3\text{cm}})^2 - (p_{1\text{cm}} - p_{3\text{cm}})^2 \qquad - 4p_{1\text{cm}}\, p_{3\text{cm}}\, \sin^2(\theta_{\text{cm}}/2)$$
$$= t_0 - 4p_{1\text{cm}}\, p_{3\text{cm}}\, \sin^2(\theta_{\text{cm}}/2) \ , \qquad (48.34)$$

where θ_{cm} is the angle between particle 1 and 3. The limiting values t_0 ($\theta_{\text{cm}} = 0$) and t_1 ($\theta_{\text{cm}} = \pi$) for $2 \to 2$ scattering are

$$t_0(t_1) = \left[\frac{m_1^2 - m_3^2 - m_2^2 + m_4^2}{2\sqrt{s}}\right]^2 - (p_{1\,\text{cm}} \mp p_{3\,\text{cm}})^2 \ . \qquad (48.35)$$

In the literature the notation t_{min} (t_{max}) for t_0 (t_1) is sometimes used, which should be discouraged since $t_0 > t_1$. The center-of-mass energies and momenta of the incoming particles are

$$E_{1\text{cm}} = \frac{s + m_1^2 - m_2^2}{2\sqrt{s}} \ , \qquad E_{2\text{cm}} = \frac{s + m_2^2 - m_1^2}{2\sqrt{s}} \ , \qquad (48.36)$$

For $E_{3\text{cm}}$ and $E_{4\text{cm}}$, change m_1 to m_3 and m_2 to m_4. Then

$$p_{i\,\text{cm}} = \sqrt{E_{i\,\text{cm}}^2 - m_i^2} \text{ and } p_{1\text{cm}} = \frac{p_{1\,\text{lab}}\, m_2}{\sqrt{s}} \ . \qquad (48.37)$$

Here the subscript lab refers to the frame where particle 2 is at rest. [For other relations see Eqs. (48.2)–(48.4).]

48.5.2. ***Inclusive reactions*** : Choose some direction (usually the beam direction) for the z-axis; then the energy and momentum of a particle can be written as

$$E = m_T \cosh y \ , \ p_x \ , \ p_y \ , \ p_z = m_T \sinh y \ , \qquad (48.38)$$

where m_T, conventionally called the 'transverse mass', is given by

$$m_T^2 = m^2 + p_x^2 + p_y^2 \ . \qquad (48.39)$$

and the rapidity y is defined by

$$y = \frac{1}{2} \ln \left(\frac{E + p_z}{E - p_z}\right)$$

$$= \ln \left(\frac{E + p_z}{m_T}\right) = \tanh^{-1}\left(\frac{p_z}{E}\right) \ . \qquad (48.40)$$

Note that the definition of the transverse mass in Eq. (48.39) differs from that used by experimentalists at hadron colliders (see Sec. 48.6.1 below). Under a boost in the z-direction to a frame with velocity β, $y \to y - \tanh^{-1}\beta$. Hence the shape of the rapidity distribution dN/dy is invariant, as are differences in rapidity. The invariant cross section may also be rewritten

$$E\frac{d^3\sigma}{d^3p} = \frac{d^3\sigma}{d\phi\, dy\, p_T\, dp_T} \Longrightarrow \frac{d^2\sigma}{\pi\, dy\, d(p_T^2)} \ . \tag{48.41}$$

The second form is obtained using the identity $dy/dp_z = 1/E$, and the third form represents the average over ϕ.

Feynman's x variable is given by

$$x = \frac{p_z}{p_{z\,\max}} \approx \frac{E + p_z}{(E + p_z)_{\max}} \quad (p_T \ll |p_z|) \ . \tag{48.42}$$

In the c.m. frame,

$$x \approx \frac{2p_{z\,\rm cm}}{\sqrt{s}} = \frac{2m_T \sinh y_{\rm cm}}{\sqrt{s}} \tag{48.43}$$

and

$$= (y_{\rm cm})_{\max} = \ln(\sqrt{s}/m) \ . \tag{48.44}$$

The invariant mass M of the two-particle system described in Sec. 48.4.2 can be written in terms of these variables as

$$M^2 = m_1^2 + m_2^2 + 2[E_T(1)E_T(2)\cosh\Delta y - \boldsymbol{p}_T(1)\cdot\boldsymbol{p}_T(2)] \ , \tag{48.45}$$

where

$$E_T(i) = \sqrt{|\boldsymbol{p}_T(i)|^2 + m_i^2} \ , \tag{48.46}$$

and $\boldsymbol{p}_T(i)$ denotes the transverse momentum vector of particle i.

For $p \gg m$, the rapidity [Eq. (48.40)] may be expanded to obtain

$$\begin{aligned} y &= \frac{1}{2}\ln\frac{\cos^2(\theta/2) + m^2/4p^2 + \ldots}{\sin^2(\theta/2) + m^2/4p^2 + \ldots} \\ &\approx -\ln\tan(\theta/2) \equiv \eta \end{aligned} \tag{48.47}$$

where $\cos\theta = p_z/p$. The pseudorapidity η defined by the second line is approximately equal to the rapidity y for $p \gg m$ and $\theta \gg 1/\gamma$, and in any case can be measured when the mass and momentum of the particle are unknown. From the definition one can obtain the identities

$$\sinh\eta = \cot\theta \ , \quad \cosh\eta = 1/\sin\theta \ , \quad \tanh\eta = \cos\theta \ . \tag{48.48}$$

48.6. Transverse variables

At hadron colliders, a significant and unknown proportion of the energy of the incoming hadrons in each event escapes down the beam-pipe. Consequently if invisible particles are created in the final state, their net momentum can only be constrained in the plane transverse to the beam direction. Defining the z-axis as the beam direction, this net momentum is equal to the missing transverse energy vector

$$\boldsymbol{E}_T^{\rm miss} = -\sum_i \boldsymbol{p}_T(i) \ , \tag{48.49}$$

where the sum runs over the transverse momenta of all visible final state particles.

48.6.1. *Single production with semi-invisible final state* :

Consider a single heavy particle of mass M produced in association with visible particles which decays as in Fig. 48.1 to two particles, of which one (labeled particle 1) is invisible. The mass of the parent particle can be constrained with the quantity M_T defined by

$$\begin{aligned} M_T^2 &\equiv [E_T(1) + E_T(2)]^2 - [\boldsymbol{p}_T(1) + \boldsymbol{p}_T(2)]^2 \\ &= m_1^2 + m_2^2 + 2[E_T(1)E_T(2) - \boldsymbol{p}_T(1) \cdot \boldsymbol{p}_T(2)] \ , \end{aligned} \qquad (48.50)$$

where

$$\boldsymbol{p}_T(1) = \boldsymbol{E}_T^{\text{miss}} \ . \qquad (48.51)$$

This quantity is called the 'transverse mass' by hadron collider experimentalists but it should be noted that it is quite different from that used in the description of inclusive reactions [Eq. (48.39)]. The distribution of event M_T values possesses an end-point at $M_T^{\max} = M$. If $m_1 = m_2 = 0$ then

$$M_T^2 = 2|\boldsymbol{p}_T(1)||\boldsymbol{p}_T(2)|(1 - \cos\phi_{12}) \ , \qquad (48.52)$$

where ϕ_{ij} is defined as the angle between particles i and j in the transverse plane.

48.6.2. *Pair production with semi-invisible final states* :

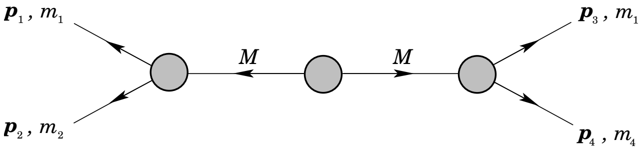


Figure 48.7: Definitions of variables for pair production of semi-invisible final states. Particles 1 and 3 are invisible while particles 2 and 4 are visible.

Consider two identical heavy particles of mass M produced such that their combined center-of-mass is at rest in the transverse plane (Fig. 48.7). Each particle decays to a final state consisting of an invisible particle of fixed mass m_1 together with an additional visible particle. M and m_1 can be constrained with the variables M_{T2} and M_{CT} which are defined in Refs. [4] and [5].

Further discussion and all references may be found in the full *Review of Particle Physics*. The numbering of references and equations used here corresponds to that version.

50. Cross-section formulae for specific processes

Revised August 2019 by H. Baer (Oklahoma U.) and R.N. Cahn (LBNL).

PART I: Standard Model Processes

Setting aside leptoproduction (for which, see Sec. 16 of this *Review*), the cross sections of primary interest are those with light incident particles, e^+e^-, $\gamma\gamma$, $q\overline{q}$, gq , gg, *etc.*, where g and q represent gluons and light quarks. The produced particles include both light particles and heavy ones - t, W, Z, and the Higgs boson H. We provide the production cross sections calculated within the Standard Model for several such processes.

50.1. Resonance Formation

Resonant cross sections are generally described by the Breit-Wigner formula (Sec. 18 of this *Review*).

$$\sigma(E) = \frac{2J+1}{(2S_1+1)(2S_2+1)}\frac{4\pi}{k^2}\left[\frac{\Gamma^2/4}{(E-E_0)^2+\Gamma^2/4}\right]B_{in}B_{out}, \quad (50.1)$$

where E is the c.m. energy, J is the spin of the resonance, and the number of polarization states of the two incident particles are $2S_1+1$ and $2S_2+1$. The c.m. momentum in the initial state is k, E_0 is the c.m. energy at the resonance, and Γ is the full width at half maximum height of the resonance. The branching fraction for the resonance into the initial-state channel is B_{in} and into the final-state channel is B_{out}. For a narrow resonance, the factor in square brackets may be replaced by $\pi\Gamma\delta(E-E_0)/2$.

50.2. Production of light particles

The production of point-like, spin-1/2 fermions in e^+e^- annihilation through a virtual photon, $e^+e^- \to \gamma^* \to f\overline{f}$, at c.m. energy squared s is

$$\frac{d\sigma}{d\Omega} = N_c\frac{\alpha^2}{4s}\beta[1+\cos^2\theta+(1-\beta^2)\sin^2\theta]Q_f^2 \ , \quad (50.2)$$

where β is v/c for the produced fermions in the c.m., θ is the c.m. scattering angle, and Q_f is the charge of the fermion. The factor N_c is 1 for charged leptons and 3 for quarks. In the ultrarelativistic limit, $\beta \to 1$,

$$\sigma = N_cQ_f^2\frac{4\pi\alpha^2}{3s} = N_cQ_f^2\frac{86.8 \text{ nb}}{s\,(\text{GeV}^2)} \ . \quad (50.3)$$

The cross section for the annihilation of a $q\overline{q}$ pair into a distinct pair $q'\overline{q}'$ through a gluon is completely analogous up to color factors, with the replacement $\alpha \to \alpha_s$. Treating all quarks as massless, averaging over the colors of the initial quarks and defining $t = -s\sin^2(\theta/2)$, $u = -s\cos^2(\theta/2)$, one finds

$$\frac{d\sigma}{d\Omega}(q\overline{q} \to q'\overline{q}') = \frac{\alpha_s^2}{9s}\frac{t^2+u^2}{s^2} \ . \quad (50.4)$$

Crossing symmetry gives

$$\frac{d\sigma}{d\Omega}(qq' \to qq') = \frac{\alpha_s^2}{9s}\frac{s^2+u^2}{t^2} \ . \quad (50.5)$$

If the quarks q and q' are identical, we have

$$\frac{d\sigma}{d\Omega}(q\overline{q} \to q\overline{q}) = \frac{\alpha_s^2}{9s}\left[\frac{t^2+u^2}{s^2}+\frac{s^2+u^2}{t^2}-\frac{2u^2}{3st}\right] \ , \quad (50.6)$$

and by crossing

$$\frac{d\sigma}{d\Omega}(qq \to qq) = \frac{\alpha_s^2}{9s}\left[\frac{t^2+s^2}{u^2} + \frac{s^2+u^2}{t^2} - \frac{2s^2}{3ut}\right] . \tag{50.7}$$

Annihilation of e^+e^- into $\gamma\gamma$ has the cross section

$$\frac{d\sigma}{d\Omega}(e^+e^- \to \gamma\gamma) = \frac{\alpha^2}{2s}\frac{u^2+t^2}{tu} . \tag{50.8}$$

The related QCD process also has a triple-gluon coupling. The cross section is

$$\frac{d\sigma}{d\Omega}(q\overline{q} \to gg) = \frac{8\alpha_s^2}{27s}(t^2+u^2)(\frac{1}{tu} - \frac{9}{4s^2}) . \tag{50.9}$$

The crossed reactions are

$$\frac{d\sigma}{d\Omega}(qg \to qg) = \frac{\alpha_s^2}{9s}(s^2+u^2)(-\frac{1}{su} + \frac{9}{4t^2}) , \tag{50.10}$$

$$\frac{d\sigma}{d\Omega}(gg \to q\overline{q}) = \frac{\alpha_s^2}{24s}(t^2+u^2)(\frac{1}{tu} - \frac{9}{4s^2}) , \tag{50.11}$$

$$\frac{d\sigma}{d\Omega}(gg \to gg) = \frac{9\alpha_s^2}{8s}(3 - \frac{ut}{s^2} - \frac{su}{t^2} - \frac{st}{u^2}) . \tag{50.12}$$

Lepton-quark scattering is analogous (neglecting Z exchange)

$$\frac{d\sigma}{d\Omega}(eq \to eq) = \frac{\alpha^2}{2s}e_q^2\frac{s^2+u^2}{t^2} , \tag{50.13}$$

e_q is the quark charge. For ν-scattering with the four-Fermi interaction

$$\frac{d\sigma}{d\Omega}(\nu d \to \ell^- u) = \frac{G_F^2 s}{4\pi^2} , \tag{50.14}$$

where the Cabibbo angle suppression is ignored. Similarly

$$\frac{d\sigma}{d\Omega}(\nu\overline{u} \to \ell^-\overline{d}) = \frac{G_F^2 s}{4\pi^2}\frac{(1+\cos\theta)^2}{4} . \tag{50.15}$$

For deep inelastic scattering (presented in more detail in Section 19) we consider quarks of type i carrying a fraction $x = Q^2/(2M\nu)$ of the nucleon's energy, where $\nu = E - E'$ is the energy lost by the lepton in the nucleon rest frame. With $y = \nu/E$ we have the correspondences

$$1 + \cos\theta \to 2(1-y) , \qquad d\Omega_{cm} \to 4\pi f_i(x) dx\, dy , \tag{50.16}$$

where the latter incorporates the quark distribution, $f_i(x)$. We find

$$\frac{d\sigma}{dx\,dy}(eN \to eX) = \frac{4\pi\alpha^2 xs}{Q^4}\frac{1}{2}\left[1+(1-y)^2\right]$$
$$\times \left[\frac{4}{9}(u(x)+\overline{u}(x)+\ldots)+\frac{1}{9}(d(x)+\overline{d}(x)+\ldots)\right] \tag{50.17}$$

where now $s = 2ME$ is the cm energy squared for the electron-nucleon collision and we have suppressed contributions from higher mass quarks.

Similarly,

$$\frac{d\sigma}{dx\,dy}(\nu N \to \ell^- X) = \frac{G_F^2 xs}{\pi}[(d(x)+\ldots)+(1-y)^2(\overline{u}(x)+\ldots)] , \tag{50.18}$$

$$\frac{d\sigma}{dx\,dy}(\overline{\nu} N \to \ell^+ X) = \frac{G_F^2 xs}{\pi}[(\overline{d}(x)+\ldots)+(1-y)^2(u(x)+\ldots)] . \tag{50.19}$$

Quasi-elastic neutrino scattering ($\nu_\mu n \to \mu^- p$, $\overline{\nu}_\mu p \to \mu^+ n$) is directly related to the crossed reaction, neutron decay.

50.3. Hadroproduction of heavy quarks

For hadroproduction of heavy quarks $Q = c,\ b,\ t$, it is important to include mass effects in the formulae. For $q\bar{q} \to Q\bar{Q}$, one has

$$\frac{d\sigma}{d\Omega}(q\bar{q} \to Q\bar{Q}) = \frac{\alpha_s^2}{9s^3}\sqrt{1 - \frac{4m_Q^2}{s}}\left[(m_Q^2 - t)^2 + (m_Q^2 - u)^2 + 2m_Q^2 s\right], \tag{50.20}$$

while for $gg \to Q\bar{Q}$ one has

$$\begin{aligned}\frac{d\sigma}{d\Omega}(gg \to Q\bar{Q}) = \frac{\alpha_s^2}{32s}\sqrt{1 - \frac{4m_Q^2}{s}}\Bigg[\frac{6}{s^2}(m_Q^2 - t)(m_Q^2 - u) \\ -\frac{m_Q^2(s - 4m_Q^2)}{3(m_Q^2 - t)(m_Q^2 - u)} + \frac{4}{3}\frac{(m_Q^2 - t)(m_Q^2 - u) - 2m_Q^2(m_Q^2 + t)}{(m_Q^2 - t)^2} \\ +\frac{4}{3}\frac{(m_Q^2 - t)(m_Q^2 - u) - 2m_Q^2(m_Q^2 + u)}{(m_Q^2 - u)^2} \\ -3\frac{(m_Q^2 - t)(m_Q^2 - u) + m_Q^2(u - t)}{s(m_Q^2 - t)} - 3\frac{(m_Q^2 - t)(m_Q^2 - u) + m_Q^2(t - u)}{s(m_Q^2 - u)}\Bigg].\end{aligned} \tag{50.21}$$

50.4. Production of Weak Gauge Bosons

50.4.1. *W and Z resonant production* :

Resonant production of a single W or Z is governed by the partial widths

$$\Gamma(W \to \ell_i \overline{\nu}_i) = \frac{\sqrt{2}G_F m_W^3}{12\pi} \tag{50.22}$$

$$\Gamma(W \to q_i \overline{q}_j) = 3\frac{\sqrt{2}G_F |V_{ij}|^2 m_W^3}{12\pi} \tag{50.23}$$

$$\begin{aligned}\Gamma(Z \to f\overline{f}) = N_c \frac{\sqrt{2}G_F m_Z^3}{6\pi} \\ \times\left[(T_3 - Q_f \sin^2\theta_W)^2 + (Q_f \sin^2\theta_W)^2\right].\end{aligned} \tag{50.24}$$

The weak mixing angle is θ_W. The CKM matrix elements are V_{ij}. N_c is 3 for $q\overline{q}$ and 1 for leptonic final states. These widths along with associated branching fractions may be applied to the resonance production formula of Sec. 50.1 to gain the total W or Z production cross section.

50.4.2. *Production of pairs of weak gauge bosons* :

The cross section for $f\overline{f} \to W^+W^-$ is given in term of the couplings of the left-handed and right-handed fermion f, $\ell = 2(T_3 - Qx_W)$, $r = -2Qx_W$, where T_3 is the third component of weak isospin for the left-handed f, Q is its electric charge (in units of the proton charge), and $x_W = \sin^2\theta_W$:

$$\begin{aligned}\frac{d\sigma}{dt} = \frac{2\pi\alpha^2}{N_c s^2}\Bigg\{\left[\left(Q + \frac{\ell + r}{4x_W}\frac{s}{s - m_Z^2}\right)^2 + \left(\frac{\ell - r}{4x_W}\frac{s}{s - m_Z^2}\right)^2\right]A(s,t,u) \\ + \frac{1}{2x_W}\left(Q + \frac{\ell}{2x_W}\frac{s}{s - m_Z^2}\right)(\Theta(-Q)I(s,t,u) - \Theta(Q)I(s,u,t)) \\ + \frac{1}{8x_W^2}(\Theta(-Q)E(s,t,u) + \Theta(Q)E(s,u,t))\Bigg\},\end{aligned} \tag{50.26}$$

where $\Theta(x)$ is 1 for $x > 0$ and 0 for $x < 0$, and where

$$A(s,t,u) = \left(\frac{tu}{m_W^4} - 1\right)\left(\frac{1}{4} - \frac{m_W^2}{s} + 3\frac{m_W^4}{s^2}\right) + \frac{s}{m_W^2} - 4,$$

$$I(s,t,u) = \left(\frac{tu}{m_W^4} - 1\right)\left(\frac{1}{4} - \frac{m_W^2}{2s} - \frac{m_W^4}{st}\right) + \frac{s}{m_W^2} - 2 + 2\frac{m_W^2}{t},$$

$$E(s,t,u) = \left(\frac{tu}{m_W^4} - 1\right)\left(\frac{1}{4} + \frac{m_W^4}{t^2}\right) + \frac{s}{m_W^2}, \tag{50.27}$$

and s, t, u are the usual Mandelstam variables with $s = (p_f + p_{\overline{f}})^2, t = (p_f - p_{W^-})^2, u = (p_f - p_{W^+})^2$. The factor N_c is 3 for quarks and 1 for leptons.

The analogous cross-section for $q_i\overline{q}_j \to W^\pm Z^0$ is

$$\begin{aligned}\frac{d\sigma}{dt} = \frac{\pi\alpha^2|V_{ij}|^2}{6s^2x_W^2}\Bigg\{&\left(\frac{1}{s - m_W^2}\right)^2\left[\left(\frac{9 - 8x_W}{4}\right)\left(ut - m_W^2 m_Z^2\right)\right.\\
&\left. + (8x_W - 6)\,s\left(m_W^2 + m_Z^2\right)\right]\\
&+ \left[\frac{ut - m_W^2 m_Z^2 - s(m_W^2 + m_Z^2)}{s - m_W^2}\right]\left[\frac{\ell_j}{t} - \frac{\ell_i}{u}\right]\\
&+ \frac{ut - m_W^2 m_Z^2}{4(1 - x_W)}\left[\frac{\ell_j^2}{t^2} + \frac{\ell_i^2}{u^2}\right] + \frac{s(m_W^2 + m_Z^2)}{2(1 - x_W)}\frac{\ell_i\ell_j}{tu}\Bigg\},\end{aligned} \tag{50.28}$$

where ℓ_i and ℓ_j are the couplings of the left-handed q_i and q_j as defined above. The CKM matrix element between q_i and q_j is V_{ij}.

The cross section for $q_i\overline{q}_i \to Z^0 Z^0$ is

$$\frac{d\sigma}{dt} = \frac{\pi\alpha^2}{96}\frac{\ell_i^4 + r_i^4}{x_W^2(1 - x_W^2)^2 s^2}\left[\frac{t}{u} + \frac{u}{t} + \frac{4m_Z^2 s}{tu} - m_Z^4\left(\frac{1}{t^2} + \frac{1}{u^2}\right)\right]. \tag{50.29}$$

50.5. Production of Higgs Bosons

50.5.1. *Resonant Production* :

The Higgs boson of the Standard Model can be produced resonantly in the collisions of quarks, leptons, W or Z bosons, gluons, or photons. The production cross section is thus controlled by the partial width of the Higgs boson into the entrance channel and its total width. The partial widths are given by the relations

$$\Gamma(H \to f\overline{f}) = \frac{G_F m_f^2 m_H N_c}{4\pi\sqrt{2}}\left(1 - 4m_f^2/m_H^2\right)^{3/2}, \tag{50.30}$$

$$\Gamma(H \to W^+W^-) = \frac{G_F m_H^3 \beta_W}{32\pi\sqrt{2}}\left(4 - 4a_W + 3a_W^2\right), \tag{50.31}$$

$$\Gamma(H \to ZZ) = \frac{G_F m_H^3 \beta_Z}{64\pi\sqrt{2}}\left(4 - 4a_Z + 3a_Z^2\right). \tag{50.32}$$

where N_c is 3 for quarks and 1 for leptons and where $a_W = 1 - \beta_W^2 = 4m_W^2/m_H^2$ and $a_Z = 1 - \beta_Z^2 = 4m_Z^2/m_H^2$. The decay to two gluons proceeds through quark loops, with the t quark dominating. Explicitly,

$$\Gamma(H \to gg) = \frac{\alpha_s^2 G_F m_H^3}{36\pi^3\sqrt{2}} \left| \sum_q I(m_q^2/m_H^2) \right|^2 , \tag{50.33}$$

where $I(z)$ is complex for $z < 1/4$. For $z < 2 \times 10^{-3}$, $|I(z)|$ is small so the light quarks contribute negligibly. For $m_H < 2m_t$, $z > 1/4$ and

$$I(z) = 3 \left[2z + 2z(1-4z) \left(\sin^{-1} \frac{1}{2\sqrt{z}} \right)^2 \right] , \tag{50.34}$$

which has the limit $I(z) \to 1$ as $z \to \infty$.

50.5.2. *Higgs Boson Production in W^* and Z^* decay* :

The Standard Model Higgs boson can be produced in the decay of a virtual W or Z ("Higgsstrahlung"): In particular, if k is the c.m. momentum of the Higgs boson,

$$\sigma(q_i\overline{q}_j \to WH) = \frac{\pi\alpha^2|V_{ij}|^2}{36\sin^4\theta_W} \frac{2k}{\sqrt{s}} \frac{k^2 + 3m_W^2}{(s - m_W^2)^2} \tag{50.35}$$

$$\sigma(f\overline{f} \to ZH) = \frac{2\pi\alpha^2(\ell_f^2 + r_f^2)}{48N_c\sin^4\theta_W\cos^4\theta_W} \frac{2k}{\sqrt{s}} \frac{k^2 + 3m_Z^2}{(s - m_Z^2)^2} . \tag{50.36}$$

where ℓ and r are defined as above.

50.5.3. *W and Z Fusion* :

Just as high-energy electrons can be regarded as sources of virtual photon beams, at very high energies they are sources of virtual W and Z beams. For Higgs boson production, it is the longitudinal components of the Ws and Zs that are important. The distribution of longitudinal Ws carrying a fraction y of the electron's energy is

$$f(y) = \frac{g^2}{16\pi^2} \frac{1-y}{y} , \tag{50.37}$$

where $g = e/\sin\theta_W$. In the limit $s \gg m_H \gg m_W$, the rate $\Gamma(H \to W_L W_L) = (g^2/64\pi)(m_H^3/m_W^2)$ and in the equivalent W approximation

$$\sigma(e^+e^- \to \overline{\nu}_e \nu_e H) = \frac{1}{16m_W^2} \left(\frac{\alpha}{\sin^2\theta_W} \right)^3 \times \left[\left(1 + \frac{m_H^2}{s} \right) \log \frac{s}{m_H^2} - 2 + 2\frac{m_H^2}{s} \right] . \tag{50.38}$$

There are significant corrections to this relation when m_H is not large compared to m_W. For $m_H = 150$ GeV, the estimate is too high by 51% for $\sqrt{s} = 1000$ GeV, 32% too high at $\sqrt{s} = 2000$ GeV, and 22% too high at $\sqrt{s} = 4000$ GeV. Fusion of ZZ to make a Higgs boson can be treated similarly. Identical formulae apply for Higgs production in the collisions of quarks whose charges permit the emission of a W^+ and a W^-, except that QCD corrections and CKM matrix elements are required. Even in the absence of QCD corrections, the fine-structure constant ought to be evaluated at the scale of the collision, say m_W. All quarks contribute to the ZZ fusion process.

Further discussion and all references may be found in the full *Review*; the equation and reference numbering corresponds to that version.

51. Neutrino Cross Section Measurements

Revised August 2019 by G.P. Zeller (FNAL).

Highlights from full review.

Neutrino cross sections are an essential ingredient in all neutrino experiments. This work summarizes accelerator-based neutrino cross section measurements performed in the $\sim 0.1 - 300$ GeV range with an emphasis on inclusive, quasi-elastic, and pion production processes, areas where we have the most experimental input at present.

Table 51.1: List of beam properties, nuclear targets, and durations for modern accelerator-based neutrino experiments studying neutrino scattering.

Experiment	beam	$\langle E_\nu \rangle$, $\langle E_{\overline{\nu}} \rangle$ GeV	neutrino target(s)	run period
ArgoNeuT	$\nu, \overline{\nu}$	4.3, 3.6	Ar	2009 – 2010
ICARUS (at CNGS)	ν	20.0	Ar	2010 – 2012
K2K	ν	1.3	CH, H_2O	2003 – 2004
MicroBooNE	ν	0.8	Ar	2015 –
MINERvA	$\nu, \overline{\nu}$	3.5 (LE), 5.5 (ME)	He, C, CH, H_2O, Fe, Pb	2009 – 2019
MiniBooNE	$\nu, \overline{\nu}$	0.8, 0.7	CH_2	2002 – 2019
MINOS	$\nu, \overline{\nu}$	3.5, 6.1	Fe	2004 – 2016
NOMAD	$\nu, \overline{\nu}$	23.4, 19.7	C–based	1995 – 1998
NOvA	$\nu, \overline{\nu}$	2.0, 2.0	CH_2	2010 –
SciBooNE	$\nu, \overline{\nu}$	0.8, 0.7	CH	2007 – 2008
T2K	ν, $\overline{\nu}$	0.6, 0.6	CH, H_2O, Fe	2010 –

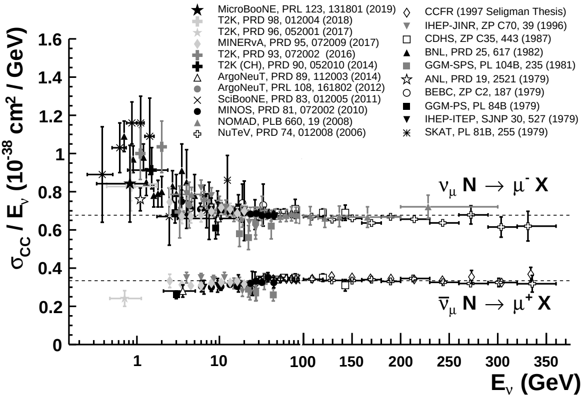


Figure 51.1: Measurements of per nucleon ν_μ and $\overline{\nu}_\mu$ CC inclusive scattering cross sections divided by neutrino energy as a function of neutrino energy. Note the transition between logarithmic and linear scales occurring at 100 GeV.

6. Atomic and Nuclear Properties of Materials

Table 6.1. Abridged from `pdg.lbl.gov/AtomicNuclearProperties` by D. E. Groom (2017). See web pages for more detail about entries in this table and for several hundred others. Quantities in parentheses are for gases at 20° C and 1 atm. Boiling points are at 1 atm. Refractive indices n are evaluated at the sodium D line blend (589.2 nm); values $\gg 1$ in brackets are for $(n-1) \times 10^6$ (gases) at 0° C and 1 atm.

Material	Z	A	$\langle Z/A \rangle$	Nucl.coll. length λ_T {g cm^{-2}}	Nucl.inter. length λ_I {g cm^{-2}}	Rad.len. X_0 {g cm^{-2}}	$dE/dx\|_{\min}$ { MeV g^{-1}cm^2}	Density {g cm^{-3}} ({g ℓ^{-1}})	Melting point (K)	Boiling point (K)	Refract. index @ Na D
H_2	1	1.008(7)	0.99212	42.8	52.0	63.05	(4.103)	0.071(0.084)	13.81	20.28	1.11[132.]
D_2	1	2.014101764(8)	0.49650	51.3	71.8	125.97	(2.053)	0.169(0.168)	18.7	23.65	1.11[138.]
He	2	4.002602(2)	0.49967	51.8	71.0	94.32	(1.937)	0.125(0.166)		4.220	1.02[35.0]
Li	3	6.94(2)	0.43221	52.2	71.3	82.78	1.639	0.534	453.6	1615.	
Be	4	9.0121831(5)	0.44384	55.3	77.8	65.19	1.595	1.848	1560.	2744.	
C diamond	6	12.0107(8)	0.49955	59.2	85.8	42.70	1.725	3.520			2.419
C graphite	6	12.0107(8)	0.49955	59.2	85.8	42.70	1.742	2.210	Sublimes at 4098. K		
N_2	7	14.007(2)	0.49976	61.1	89.7	37.99	(1.825)	0.807(1.165)	63.15	77.29	1.20[298.]
O_2	8	15.999(3)	0.50002	61.3	90.2	34.24	(1.801)	1.141(1.332)	54.36	90.20	1.22[271.]
F_2	9	18.998403163(6)	0.47372	65.0	97.4	32.93	(1.676)	1.507(1.580)	53.53	85.03	[195.]
Ne	10	20.1797(6)	0.49555	65.7	99.0	28.93	(1.724)	1.204(0.839)	24.56	27.07	1.09[67.1]
Al	13	26.9815385(7)	0.48181	69.7	107.2	24.01	1.615	2.699	933.5	2792.	
Si	14	28.0855(3)	0.49848	70.2	108.4	21.82	1.664	2.329	1687.	3538.	3.95
Cl_2	17	35.453(2)	0.47951	73.8	115.7	19.28	(1.630)	1.574(2.980)	171.6	239.1	[773.]
Ar	18	39.948(1)	0.45059	75.7	119.7	19.55	(1.519)	1.396(1.662)	83.81	87.26	1.23[281.]
Ti	22	47.867(1)	0.45961	78.8	126.2	16.16	1.477	4.540	1941.	3560.	
Fe	26	55.845(2)	0.46557	81.7	132.1	13.84	1.451	7.874	1811.	3134.	
Cu	29	63.546(3)	0.45636	84.2	137.3	12.86	1.403	8.960	1358.	2835.	
Ge	32	72.630(1)	0.44053	86.9	143.0	12.25	1.370	5.323	1211.	3106.	
Sn	50	118.710(7)	0.42119	98.2	166.7	8.82	1.263	7.310	505.1	2875.	
Xe	54	131.293(6)	0.41129	100.8	172.1	8.48	(1.255)	2.953(5.483)	161.4	165.1	1.39[701.]
W	74	183.84(1)	0.40252	110.4	191.9	6.76	1.145	19.300	3695.	5828.	
Pt	78	195.084(9)	0.39983	112.2	195.7	6.54	1.128	21.450	2042.	4098.	
Au	79	196.966569(5)	0.40108	112.5	196.3	6.46	1.134	19.320	1337.	3129.	
Pb	82	207.2(1)	0.39575	114.1	199.6	6.37	1.122	11.350	600.6	2022.	
U	92	[238.02891(3)]	0.38651	118.6	209.0	6.00	1.081	18.950	1408.	4404.	

Air (dry, 1 atm)	0.49919	61.3	90.1	36.62	(1.815)	(1.205)		78.80	
Shielding concrete	0.50274	65.1	97.5	26.57	1.711	2.300			
Borosilicate glass (Pyrex)	0.49707	64.6	96.5	28.17	1.696	2.230			
Lead glass	0.42101	95.9	158.0	7.87	1.255	6.220			
Standard rock	0.50000	66.8	101.3	26.54	1.688	2.650			
Methane (CH_4)	0.62334	54.0	73.8	46.47	(2.417)	(0.667)	90.68	111.7	[444.]
Butane (C_4H_{10})	0.59497	55.5	77.1	45.23	(2.278)	(2.489)	134.9	272.6	
Octane (C_8H_{18})	0.57778	55.8	77.8	45.00	2.123	0.703	214.4	398.8	
Paraffin ($CH_3(CH_2)_{n\approx 23}CH_3$)	0.57275	56.0	78.3	44.85	2.088	0.930			
Nylon (type 6, 6/6)	0.54790	57.5	81.6	41.92	1.973	1.18			
Polycarbonate (Lexan)	0.52697	58.3	83.6	41.50	1.886	1.20			
Polyethylene ($[CH_2CH_2]_n$)	0.57034	56.1	78.5	44.77	2.079	0.89			
Polyethylene terephthalate (Mylar)	0.52037	58.9	84.9	39.95	1.848	1.40			
Polyimide film (Kapton)	0.51264	59.2	85.5	40.58	1.820	1.42			
Polymethylmethacrylate (acrylic)	0.53937	58.1	82.8	40.55	1.929	1.19			1.49
Polypropylene	0.55998	56.1	78.5	44.77	2.041	0.90			
Polystyrene ($[C_6H_5CHCH_2]_n$)	0.53768	57.5	81.7	43.79	1.936	1.06			1.59
Polytetrafluoroethylene (Teflon)	0.47992	63.5	94.4	34.84	1.671	2.20			
Polyvinyltoluene	0.54141	57.3	81.3	43.90	1.956	1.03			1.58
Aluminum oxide (sapphire)	0.49038	65.5	98.4	27.94	1.647	3.970	2327.	3273.	1.77
Barium flouride (BaF_2)	0.42207	90.8	149.0	9.91	1.303	4.893	1641.	2533.	1.47
Carbon dioxide gas (CO_2)	0.49989	60.7	88.9	36.20	1.819	(1.842)			[449.]
Solid carbon dioxide (dry ice)	0.49989	60.7	88.9	36.20	1.787	1.563	Sublimes at 194.7 K		
Cesium iodide (CsI)	0.41569	100.6	171.5	8.39	1.243	4.510	894.2	1553.	1.79
Lithium fluoride (LiF)	0.46262	61.0	88.7	39.26	1.614	2.635	1121.	1946.	1.39
Lithium hydride (LiH)	0.50321	50.8	68.1	79.62	1.897	0.820	965.		
Lead tungstate ($PbWO_4$)	0.41315	100.6	168.3	7.39	1.229	8.300	1403.		2.20
Silicon dioxide (SiO_2, fused quartz)	0.49930	65.2	97.8	27.05	1.699	2.200	1986.	3223.	1.46
Sodium chloride (NaCl)	0.47910	71.2	110.1	21.91	1.847	2.170	1075.	1738.	1.54
Sodium iodide (NaI)	0.42697	93.1	154.6	9.49	1.305	3.667	933.2	1577.	1.77
Water (H_2O)	0.55509	58.5	83.3	36.08	1.992	1.000(0.756)	273.1	373.1	1.33
Silica aerogel	0.50093	65.0	97.3	27.25	1.740	0.200	(0.03 H_2O, 0.97 SiO_2)		

Table 4.1. Revised June 2019 by D.E. Groom (LBNL). The atomic number (top left) is the number of protons in the nucleus. The atomic masses (bottom) of stable elements are weighted by isotopic abundances in the Earth's surface. Atomic masses are relative to the mass of ^{12}C, defined to be exactly 12 unified atomic mass units (u) (1 u $\approx$ 1 g/mole). The exceptions are Th, Pa, and U, which have no stable isotopes but do have characteristic terrestrial compositions. Relative isotopic abundances often vary considerably, both in natural and commercial samples; this is reflected in the number of significant figures given for the mass. Masses may be found at `http://physics.nist.gov/pml/atomic-weights-and-isotopic-compositions-relative-atomic-masses`. If there is no stable isotope, the atomic mass of the most stable isotope known as of June 2019 is given in parentheses.

PERIODIC TABLE OF THE ELEMENTS

1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIII	9 VIII	10 VIII	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1 H hydrogen 1.008																	2 He helium 4.002602
3 Li lithium 6.94	4 Be beryllium 9.012182											5 B boron 10.81	6 C carbon 12.0107	7 N nitrogen 14.007	8 O oxygen 15.999	9 F fluorine 18.998403163	10 Ne neon 20.1797
11 Na sodium 22.98976928	12 Mg magnesium 24.305											13 Al aluminum 26.9815385	14 Si silicon 28.085	15 P phosph. 30.973761998	16 S sulfur 32.06	17 Cl chlorine 35.45	18 Ar argon 39.948
19 K potassium 39.0983	20 Ca calcium 40.078	21 Sc scandium 44.955908	22 Ti titanium 47.867	23 V vanadium 50.9415	24 Cr chromium 51.9961	25 Mn manganese 54.938044	26 Fe iron 55.845	27 Co cobalt 58.933195	28 Ni nickel 58.6934	29 Cu copper 63.546	30 Zn zinc 65.38	31 Ga gallium 69.723	32 Ge german. 72.630	33 As arsenic 74.921595	34 Se selenium 78.971	35 Br bromine 79.904	36 Kr krypton 83.798
37 Rb rubidium 85.4678	38 Sr strontium 87.62	39 Y yttrium 88.90584	40 Zr zirconium 91.224	41 Nb niobium 92.90637	42 Mo molybd. 95.95	43 Tc technet. (97.907212)	44 Ru ruthen. 101.07	45 Rh rhodium 102.90550	46 Pd palladium 106.42	47 Ag silver 107.8682	48 Cd cadmium 112.414	49 In indium 114.818	50 Sn tin 118.710	51 Sb antimony 121.760	52 Te tellurium 127.60	53 I iodine 126.90447	54 Xe xenon 131.293
55 Cs cesium 132.90545196	56 Ba barium 137.327	57–71 Lantha- nides	72 Hf hafnium 178.49	73 Ta tantalum 180.94788	74 W tungsten 183.84	75 Re rhenium 186.207	76 Os osmium 190.23	77 Ir iridium 192.217	78 Pt platinum 195.084	79 Au gold 196.966569	80 Hg mercury 200.592	81 Tl thallium 204.38	82 Pb lead 207.2	83 Bi bismuth 208.98040	84 Po polonium (208.98243)	85 At astatine (209.98715)	86 Rn radon (222.01758)
87 Fr francium (223.01974)	88 Ra radium (226.02541)	89–103 Actinides	104 Rf rutherford. (267.12169)	105 Db dubnium (268.12567)	106 Sg seaborgium (269.12863)	107 Bh bohrium (270.13336)	108 Hs hassium (269.13375)	109 Mt meitnerium (278.1563)	110 Ds darmstadt. (281.1645)	111 Rg roentgen. (282.16912	112 Cn copernicium (285.17712)	113 Nh nihonium (286.18221)	114 Fl flerovium (289.19042)	115 Mc moscovium (290.19598)	116 Lv livermorium (293.20449)	117 Ts tennessine (294.2105)	118 Og oganesson (294.21392)

Lanthanide series

57 La lanthan. 138.90547	58 Ce cerium 140.116	59 Pr praseodym. 140.90765	60 Nd neodym. 144.242	61 Pm prometh. (144.91276)	62 Sm samarium 150.36	63 Eu europium 151.964	64 Gd gadolin. 157.25	65 Tb terbium 158.92535	66 Dy dyspros. 162.500	67 Ho holmium 164.93033	68 Er erbium 167.259	69 Tm thulium 168.93422	70 Yb ytterbium 173.054	71 Lu lutetium 174.9668

Actinide series

89 Ac actinium (227.02775)	90 Th thorium 232.0377	91 Pa protactin. 231.03588	92 U uranium 238.02891	93 Np neptunium (237.04817)	94 Pu plutonium (244.06420)	95 Am americ. (243.06138)	96 Cm curium (247.07035)	97 Bk berkelium (247.07031)	98 Cf californ. (251.07959)	99 Es einstein. (252.08298)	100 Fm fermium (257.09511)	101 Md mendelev. (258.09844)	102 No nobelium (259.10103)	103 Lr lawrenc. (262.10961)

2020

JULY

S	M	T	W	T	F	S
			1	2	3	4
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12	13	14	15	16	17	18
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AUGUST

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16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

SEPTEMBER

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20	21	22	23	24	25	26
27	28	29	30			

OCTOBER

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18	19	20	21	22	23	24
25	26	27	28	29	30	31

NOVEMBER

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22	23	24	25	26	27	28
29	30					

DECEMBER

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27	28	29	30	31		

2021

JULY

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18	19	20	21	22	23	24
25	26	27	28	29	30	31

AUGUST

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SEPTEMBER

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OCTOBER

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NOVEMBER

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DECEMBER

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2021

JANUARY

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24	25	26	27	28	29	30
31						

FEBRUARY

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28						

MARCH

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28	29	30	31			

APRIL

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25	26	27	28	29	30	

MAY

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23	24	25	26	27	28	29
30	31					

JUNE

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2022

JANUARY

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23	24	25	26	27	28	29
30	31					

FEBRUARY

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MARCH

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APRIL

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24	25	26	27	28	29	30

MAY

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29	30	31				

JUNE

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12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

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